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COST BENEFIT ANALYSIS OF IMPLEMENTING BUILDING INFORMATION MODELING (BIM) FOR CONSTRUCTION MANAGEMENT OF THE SPORTS ARENA OF UNIVERSITY OF ALASKA ANCHORAGE

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A

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By

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Abstract

This research project evaluates the costs and benefits of implementing building information modeling (BIM) as a construction project management tool through the scenario analysis of the UAA Sports Arena project completed August 14, 2014. A literature review was conducted providing general information about BIM, its current status, leading software, cost, benefits, and analysis of two case studies. Cost benefit analysis was applied to account for risk and allow for the comparison of multiple scenarios that are simulated in @RISK. Based on the schedule scenario the project could have ended 11 days early, resulting in an estimated savings of 1.5% of total project cost. Based on the cost scenario the project is estimated to save 1.1% of total project cost, with a 72.8% chance of realizing a positive benefit. When the conditions specific to each scenario in this research are met, the results support a go decision with regards to the implementation of BIM.

Keywords: BIM; CBA; @RISK

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Chapter 1 Introduction

This research project evaluates the costs and benefits of implementing building information modeling (BIM) as a construction project management tool through the scenario analysis of the UAA Sports Arena project completed August 14, 2014. This chapter defines the problem, research question, scope, significance, and assumptions.

1.1 Problem Statement

"Can we use BIM for construction project management to assist with problem solving, and assist to keep projects on time and under budget?" Bercerik-Gerber (2010), the problem at the core of the question by Bercerik-Gerber is how to gather, interpret, and share information in a way that is usable, reliable, and efficient. Gallaher (2004) provides additional context to this problem through research results describing how poor inter-operability and data management cost the building industry approximately $15.8 billion a year, or approximately 3-4% of total industry turnover. To summarize, there are multiple features of work involved in the management of a construction project that generate significant amounts of data. This data is not being as efficiently managed as it potentially could be. Due to this inefficient management, the result is a loss of funds that could be otherwise better utilized. For example, in regards to the UAA Sports Arena, the university would have been able to procure additional features of work that would further enhance the end users' experience such as a more advanced scoreboard, enhanced sound system, or radiant heat for the sidewalks.

1.2 Research Question

The research question at the core of this project is, "What are the costs and benefits of implementing BIM as a construction management tool on a recently completed construction project?" This question will be applied to the new UAA Sports Arena, currently named the Alaska Airlines Center, through scenario analysis.

1.3 Scope

The scope of this research is to conduct a scenario analysis of the implementation of BIM through forecasting the total change to the UAA Sports Arena's project cost and schedule. The results of the scenario analysis can be used to inform management whether or not BIM should be used in future construction projects. To complete this scope, this research project focused on three areas:

- The content and current status of BIM.
- The trends of implementation of BIM.
- The decision making of implementation of BIM.

1.4 Significance

The significance of this research is it provides practical scenario analysis to justify the pros and cons of using BIM. The results of this research project inform a go vs. no-go decision on implementing BIM for construction project management. This research contributes to the developing body of knowledge of BIM as a management tool during the construction phase in the lifecycle of a product. Information contained in this project provides a case study of sports arena construction in Alaska for utilization in support of future research.

1.5 Assumptions

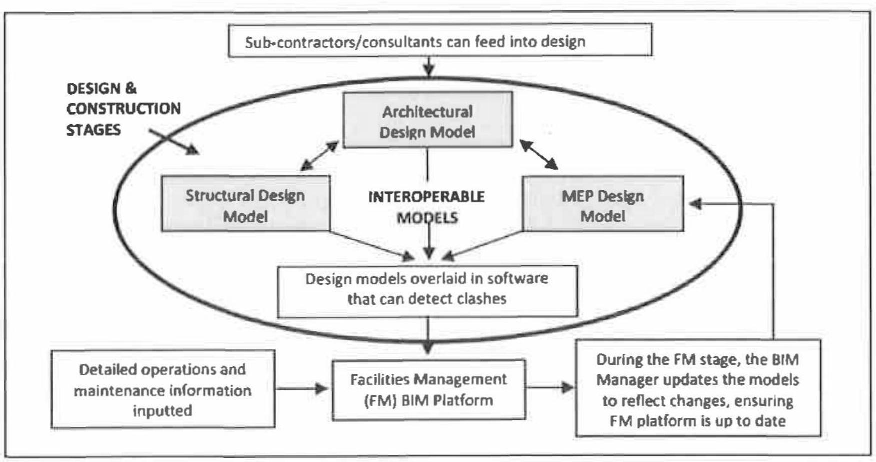
This project assumes the reader has general experience with the construction industry, its practices, and terminologies. During evaluation of the UAA Sports Arena scenario, all project related costs and schedule items are evaluated separately and are assumed complete as of September 30, 2014. Due to the timing of this project the UAA Sports Arena is currently in its 1-year warranty period and there are outstanding costs. The outstanding costs amount to less than 1% of the total project budget and can be assumed to have a minimal impact on the results of the scenario analysis. To simplify the scenario analysis, the scheduled was evaluated at the level three work package and all start dates are consider fixed. This project does not consider product lifecycle management focusing specifically on BIM's application to construction project management.

Chapter 2 Literature Review

This literature review was conducted to provide the reader foundational knowledge and discuss issues relevant to BIM. This chapter will outline general information, BIM's current status, leading software, costs, benefits, and a review two comparable case studies.

2.1 Building Information Modeling

The primary focus of this project is regarding the implementation of BIM on the construction phase of a product's lifecycle. The following chart graphically displays how BIM would be managed during this phase.



Thurairajah, N., & Dan, G. (2013)
Figure 2.1 Interoperable Models

Figure 2.1 shows that BIM is not only useful for design and construction applications, but BIM can extend to the entire product lifecycle, allowing owners to efficiently manage their facilities. The rest of this section will provide further details about what BIM is and how it's utilized. To begin with, this research will look to the U.S. government National Institute of Building Sciences.

According to the National Institute of Building Sciences (2012), a building information model is a digital representation of the physical and the functional characteristic of a facility. BIM is different from making a drawing in 2-D or 3-D CAD. To create a BIM, a modeler uses intelligent objects to build the model, which can incorporate 3-D shape information, 4-D schedule and time related information, and 5-D a cost dimension which can be incorporated into the BIM or linked to other associated building objects. This improves the ability of the project team to share information efficiently. It assists during the construction phase by providing timely information to make informed decisions, assist with the monitoring and controlling, and allows for efficient application of other management techniques such as earned value management where you analyze the relationship between cost and schedule to evaluate project status.

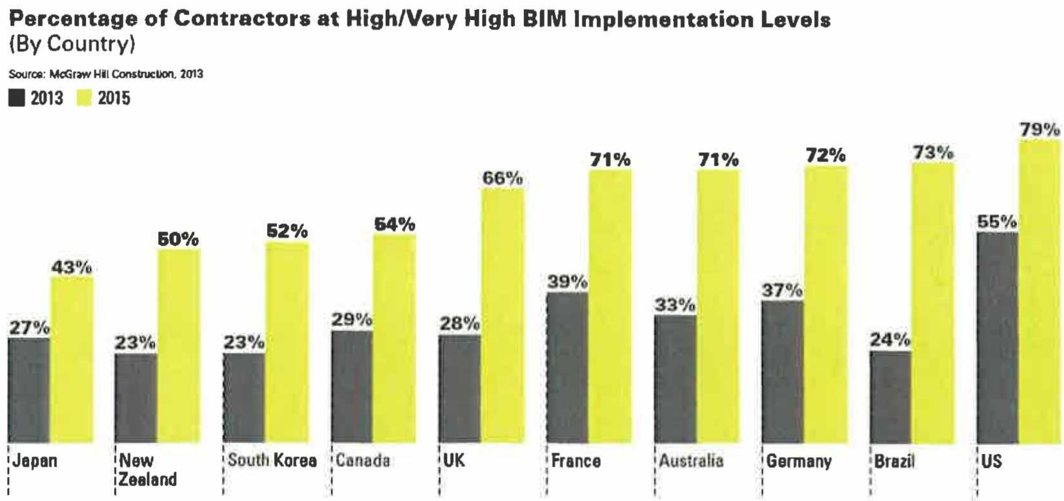
Regarding the perceived value of building information modeling in the U.S. building industry, Becerik-Gerber (2010), the successful completion of a project requires the collaboration of numerous parties sometimes separated geographically, and for a project to be successful, a project needs continuous, accurate, and real-time information shared among project participants to facilitate the resolution of conflicts, assist with problem solving, and help keep projects on-time and under budget. Poor inter-operability and data management cost the building industry approximately $15.8 billion a year, or approximately 3-4% of the total industry turnover (Gallaher et al., 2004). The previous information reflects the need to increase efficiency in project delivery methods and BIM is a tool for accomplishing this goal.

Popov et al., (2009) examined the use of a virtual building design and construction model for developing an effective project concept in a 5D environment. The research describes one of the primary responsibilities of a construction project manager, collaboration, and introduces product lifecycle management (PLM). PLM includes typical 2D plans and specifications, 3D geometric model completed using computer aided drafting software, 4D schedule and time, and 5D cost. The research summarizes a theoretical approach to construction project management that utilizes 3D software to facilitate the design and planning for a construction project. It is then populated with schedule and cost related information to allow for PLM, which is not limited to design and construction, but also allows for facility project close-out and maintenance. The advantage to construction project management is the application of total project management, the ability to utilize BIM to plan, design, and build the project, and then turn over the completed as-built model during the close-out phase to the owner so the facility can be more efficiently managed.

Mahaligam et al., (2009) conducted an evaluation of the applicability of 4D CAD on construction projects. The research contributes to the understanding of how 4D models can be introduced, positioned and implemented on construction sites, so as to maximize both their acceptability and their usefulness. The largest value of 4D CAD is in the scope development, planning, and construction stage, with an emphasis with improving communication between various stakeholders. Based on professional experience, the primary goal of any construction project manager is effective communication, but what the research failed to consider is about the broader implications of BIM, specifically on how it can be utilized to report as-built information from trade professionals in the field, allowing for real-time construction progress monitoring.

2.2 The Status of BIM Today

Gilmore et al., (2014) on behalf of McGraw Hill Construction released a report "The Business value of BIM for Construction in Major Global Markets: How Contractors around the World are Driving Innovation with Building Information Modeling," the research behind the report provides information on the status of BIM in today's global market. Key findings are that three quarters of the construction companies surveyed report a positive return on investment (ROI) on their BIM program. There are fewer errors and omissions, less rework and lower construction costs. Over the next two years, contractors expect the percentage of their work that involves BIM will increase by 50% on average. The data was evaluated in 2013, so the estimated increase is projected to occur by 2015. The ROI of BIM is directly related to experience utilizing BIM, and contractors in all markets are planning to expand their investments in BIM programs over the next two years. Figure 2.2 shows 2013 BIM implementation levels and 2015 projections. The U.S. currently has the highest level of implementation, which also shows the increasing trend of BIM implementation globally.



Gilmore et al., (2014).

Figure 2.2 Percentages of Contractors at High/Very High BIM Implementation Level

Government mandates are also driving BIM implementation (Gilmore et al., 2014) in multiple countries such as in the UK, Singapore, Norway, Finland, and the U.S. In the UK, model-based BIM will be mandatory on all public sector projects by 2016. In Singapore, they have implemented a BIM-based rapid building permitting system. In Norway, the civil state client Statsbygg has mandated BIM use for the lifecycle of their buildings and by 2010 all of their projects were using the industry foundation class file format. In Finland, the state property services agency has required the use of BIM for its project since 2007. In the U.S., the General Services Administration (GSA) is moving towards requiring BIM and is working to evolve the National BIM Standard (NBIMS 3.0) to be released in 2014. This highlights that government agencies around the world are one of the primary factors driving BIM, because they recognize the increased savings and transparency that modeling allows for. The ability to model and have readily available as-built information is crucial for successful maintenance of our built environment.

BIM has multiple applications during the various phases of a project (Gilmore et al., 2014). During the design phase, BIM is utilized to conduct multi-trade coordination, visualization of design intent, determining quantities from a model, integration of model with schedule (4D), and integration of model with costs (5D). During the construction phase, BIM is utilized to perform model-driven layout in the field, model-driven prefabrication, status/progress monitoring, and augmented reality to visualize the model and existing conditions together. It also utilizes laser scanning during construction to validate compliance with the model, supply chain management, integrating the model with GPS to control construction equipment onsite, and mode-driven robotics onsite. During the closeout phase, BIM is utilized to prepare the final as-built model for the owner, adding maintenance and operations data, integration with the model for punch list and close-out activities, managing the model for the owner beyond closeout.

Future trends of BIM include the use of the cloud to host and access a BIM (Gilmore et al., 2014), which has some challenges with respect to information security; however, research continues to progress in that direction and will be an area of future growth and development. Future trends are in automated real-time construction progress monitoring.

Kim et al., (2012) researched automated construction progress measurement using a 4D building information model and 3D data. The purpose was to develop an accurate, essentially fully automated method for construction progress measuring using a 4D BIM in connection with 3D data that is collected with remote-sensing technology. The research method was able to measure and track effectively major structural components but was limited to the exterior of the building. The primary challenge of their method was the ability to track progress of multiple interior systems such as major mechanical and electrical components, and building finishes (paint, drywall, furniture, etc…).

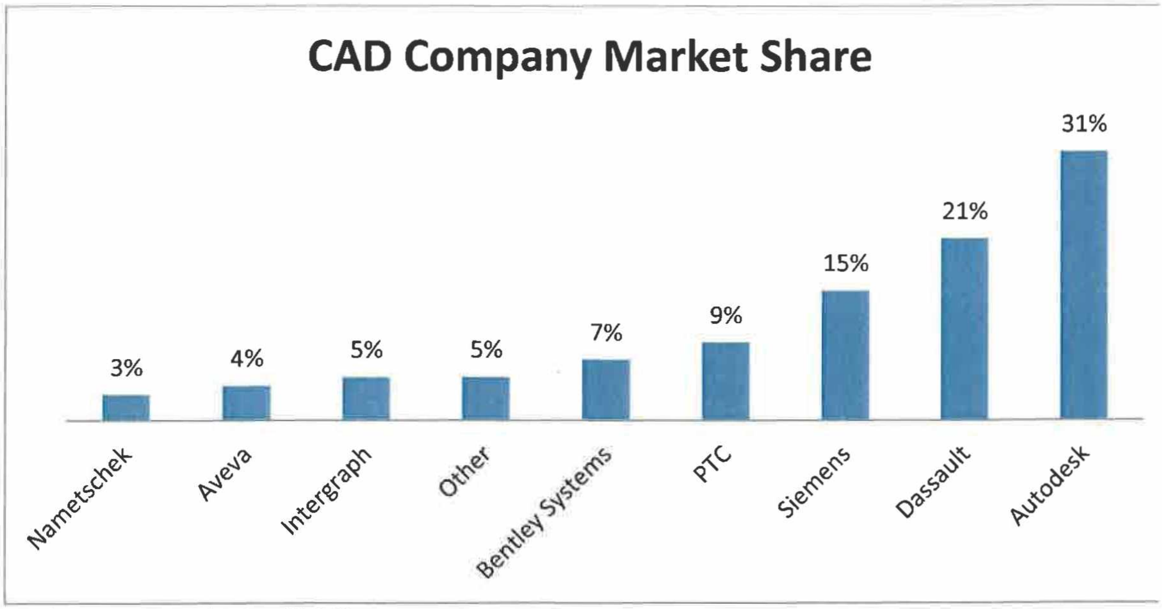
Research by Roh et al., (2010) provides a path for solving the problem of real-time progress monitoring of interior features of work through studying an object-based 3D walk through model for interior construction progress monitoring. The research highlights the usefulness of construction progress photos to which software can be applied to interpret and analyzing daily construction progress. This information can then be compared to a building information model paving the way for real-time construction progress monitoring.

Golparvar-Fard et al., (2011) researched integrated sequential as-built and as-planned representation with DAR tools in support of decision making tasks in the AEC/FM industry. DAR is a four dimensional augmented-reality model with the objective of automatically reconstruction as-built point cloud models from daily site photographs. It automatically registers point-cloud models to generate 4D as-built point-cloud models, superimpose 4D point cloud models onto a 4D BIM model, and use the resulting information to allow for real-time decision making. This research could have significant impacts for how construction project management is performed by providing real-time updates to construction management to allow for rapid decision making, which can save time and subsequently save money.

2.3 BIM Software

Kia (2013) performed a review of BIM software packages based on asset management. The research outlined the current BIM software and concluded that BIM software is not design analysis software and is not intended to evaluate the structural integrity of the design, but rather is intended to analyze potential errors, omissions and conflicts with the various design elements. This is important to understand because despite rapid technological advancements, it will be challenging to entirely remove and eliminate human error.

The dominant industry recognized software's are the following: Revit by Autodesk, Bentley Systems and Graphisoft. Revit is designed by Autodesk specifically for BIM, allowing the user to make changes that coordinate with other features of work at any time, which assist with design and document coordination. Bentley is based upon Microsoft Station technologies. Its primary user is the Army Corps of Engineers and is considered to be more robust then Revit, but requires more of a cost investment to develop proficient use. ArchiCAD by Graphisoft was a drafting program developed in the early 1980's for Apple Macintosh computers. As displayed in Figure 2.3, Autodesk currently has the largest market share.



Maher, K. (2012, April 18).
Figure 2.3 Market share for major CAD companies in 2011

2.4 The Cost of Using BIM

Research conducted by Giel and Issa (2013) explored return on investment analysis using building information modeling in construction. The research addressed the concerns that BIM has a high initial cost that outweighs its benefits addressing this concern by developing a ROI model to evaluate multiple construction projects. The research outlined a methodology that can be applied to a completed construction project to estimate the potential return on investment of BIM. In their research they documented the costs of BIM as a percent of the total project costs, which they referred to as a capitalization rate set at up to 5%. The capitalization rate is inclusive of the costs associated with equipment, software, training, development, and implementation.

There are other challenges with BIM that need to be carefully considered as outlined in research by Azhar et al., (2011) regarding building information modeling (BIM) and its benefits, risks and challenges. Challenges such as the legal risks around data ownership, responsibility for data entry and the general risk for inaccuracies, a lack of standardization of BIM specifically in regards to cost and schedule loading of BIM, and no clear consensus on how BIM should be implemented. The challenges are further supported by research conducted by Bryde et al., (2012) regarding the project benefits of BIM, with negative benefits reported primarily around the use of BIM software and a general lack of awareness, education, and training. Table 2.1 summarizes their findings in regards to frequency of negative benefits resulting from using BIM.

Table 2.1 Negative Benefit of BIM

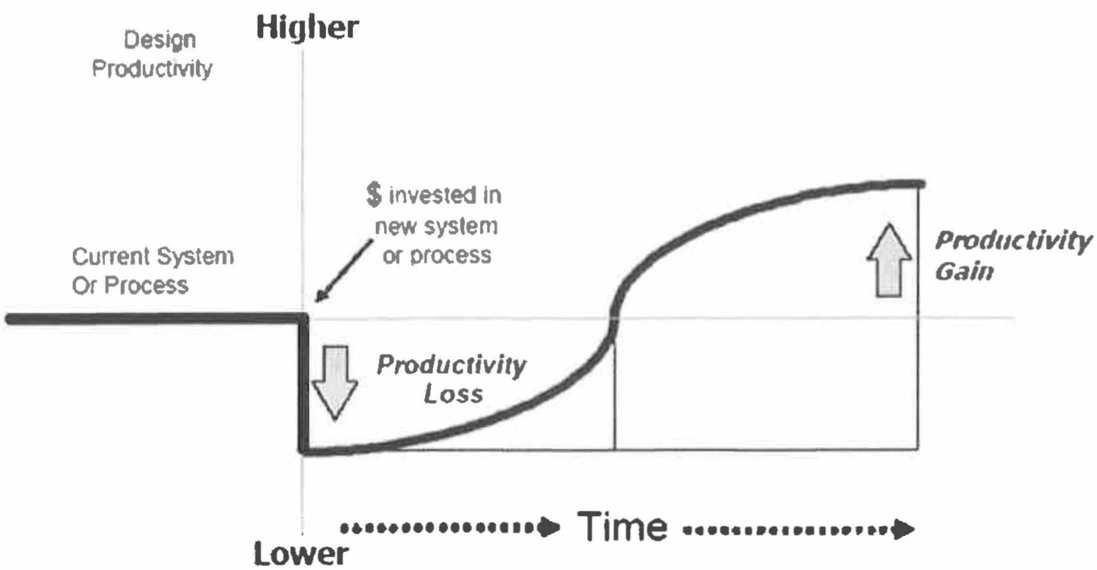
The success criteria raking of BIM use			
	Negative benefit		
Success criterion	Total instances	Total number of projects	% of total projects
Cost reduction or control	3	2	5.71%
Time reduction or control	4	3	8.59%
Communication improvement	0	0	0.00%
Coordination improvement	7	3	8.57%
Quality increase or control	0	0	0.00%
Negetive risk reduction	2	1	2.86%
Scope Clarification	0	0	0.00%
Organization improvement	2	2	5.71%
Software Issues	9	7	20.00%

Bryde et al., (2012).

2.5 The Benefits of BIM

Figure 2.4 was developed by Autodesk and is representative of the costs and benefits of BIM. An initial investment in BIM leads to an initial productivity loss.

Overtime as the project team becomes more experienced, they realize increased productivity which results in costs savings.



BIM's Return on Investment. (2007).
Figure 2.4 Benefits of BIM over time

Research by Azhar et al., (2011) outlined a number of BIM benefits, and provides specific quantifiable metrics for application to cost and schedule data which is the intent of the project. These benefits are as follows:

- Faster and more effective process – information is more easily shared, can be value-added and reused as needed.
- Better design – building proposal can be rigorously analyze, simulations can be performed quickly and performance benchmarks, enabling improved and innovative solutions.

- Controlled whole-life costs and environment data – environmental performance is more predictable, lifecycle costs are better understood.
- Better production quality – documentation output is flexible and exploits automation.
- Automated assembly – digital product data can be exploited in downstream process and be used for manufacturing/assembling of structure systems.
- Better customer service – proposals are better understood through accurate visualization.
- Lifecycle data – requirement, design, construction and operational information can be used in facilities management.

Applicable statistics cited in the research by Azhar are from Stanford University Center for Integrated Facilities Engineering (CIFE, 2007), which collected data on 32 major projects that used BIM indicated specific percentage related benefits such as:

- Up to 40% elimination of unbudgeted change.
- Cost estimation accuracy within 3%.
- Up to 80% reduction in the time taken to generate a cost estimate.
- A saving up to 10% of the contract value through class detection.
- Up to 7% reduction in project schedule.

Research conducted by Bryde et al., (2012) regarding the project benefits of BIM support the general conclusions of Azar. Their research reviewed 35 construction projects that utilized BIM and realized that the most frequently reported benefit of BIM are related to cost reduction and control, which equates to change reduction and schedule reduction. Table 2.1 summarized the negative benefits of BIM while Table 2.2 summarizes the positive benefits of BIM resulting from Bryde's research.

Table 2.1 Positive Benefit of BIM

The success criteria raking of BIM use

	Positive benefit		
Success criterion	Total instances	Total number of projects	% of total project
Cost reduction or control	29	21	60.00%
Time reduction or control	17	12	34.29%
Communication improvement	15	13	37.14%
Coordination improvement	14	12	34.29%
Quality increase or control	13	12	34.29%
Negetive risk reduction	8	6	17.14%
Scope Clarification	3	3	8.57%
Organization improvement	2	2	5.71%
Software Issues	0	0	0.00%

Bryde et al., (2012).

To conduct CBA of BIM on the UAA Sports Arena, this project will rely on the work completed by Azhar et al., (2011), which will assist with developing estimated cost impact ranges. The above benefits are still in-line with more recent research conducted by Gilmore et al., (2014).

2.6 BIM Benefits Comparable Case Studies

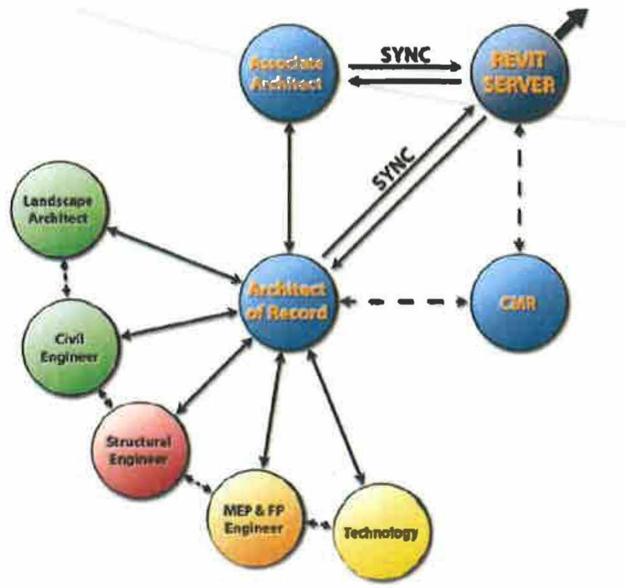
In addition to journal articles citing the benefits of BIM, it is important to look at comparable case studies, in this instance, previously completed sports arenas and the impact BIM had on their construction.

Robins & Morton was the construction manager for a new basketball arena at Auburn University in Auburn, Alabama, with a total project cost of $92.5 million. The facility included in summary two-court practice facilities, student locker rooms, a sports medicine facility, team meeting rooms, ticket office, team store, and a food court.

Robins & Morton used the Autodesk suite to assist with the design and management of the project. Using the software, they were able to increase coordination, avoid waste, simulate construction, and streamline the design-build process. Through management of the as-built construction in the model they were able to offer their client a $300,000 credit.

The Robins & Morton study is useful in confirming benefits previously cited in the literature survey, benefits such as project coordination, clash-detection, and a reduction in unbudgeted changes. This case study fails to provide real specific numbers and data, and fails to disclose the actual costs of using BIM. The next case study provides data that represents the potential benefits of using BIM on a project comparable to the UAA Sports Arena project.

The Pegula Ice Arena in University Park, PA, was substantially complete in September 2013 ahead of schedule and under budget. The project scope was a 228,000 SF 6,000 seat ice arena, with two National Hockey League (NHL) regulation size ice surfaces, and built to achieve LEED Silver Certification with an $81 million construction budget. BIM's major uses on this project were to improve design quality, assist with communication and visualization, coordination, student athlete recruitment, record modeling, logistics and safety planning, computerize automatic virtual environment (CAVE), prefabrication, design to fabrication, operations and maintenance, operations simulation, sales and marketing, 4D modeling. A BIM execution plan was developed for this project displayed in Figure 2.5.



Integrated Team Utilizes Advanced Tools and Processes to Deliver the New Pegula Ice Arena. (2014).
Figure 2.5 BIM Execution Plan

The BIM execution plan allowed for real time coordination between project team members during design and through implementation of the construction project. Through implementation of BIM, the project was able to apply a number of BIM savings which resulted in the project saving \$260K on schedule, \$475.5K using CAVE (change orders), \$200K on disruption avoidance (change orders), \$100K on design to prefab, \$161K on coordination (class detection) issues. This amounted to a total project savings of \$1.2 million which is 1.4% of the project costs. The issue this case-study does not address is the actual cost of BIM implementation, whether BIM implementation had cost 1.5% of the project costs the above cost savings alone would not have justified BIM's use.

The two previous case studies display that BIM, as it's currently being utilized, provides positive benefits to a construction project, resulting in cost savings. Cost savings are realized primarily in regards to schedule, class detection, and change order reduction. This provides information that can be used to conduct CBA on comparable construction projects.

Chapter 3 Methodology

The research question introduced in section 1.4 asks, “What are the costs and benefits of implementing BIM as a construction management tool on a recently completed construction project?” The goal of this project is to conduct a CBA through scenario analysis of cost and schedule data collected from the UAA Sports Arena project to determine if there could have been a benefit to implementing BIM during the construction phase. This chapter discusses CBA, CBA development, @RISK scenario analysis, and assumptions.

3.1 Cost Benefit Analysis

A cost benefit analysis is used for this project because it is an effective way to account for the risks involved with estimating the effects of implementing BIM on a construction project that has already been completed. CBA allows for the accounting of both tangible and intangible costs and benefits. CBA is comparative, allowing for evaluation of alternatives that can have different impacts (Downey and Roman, 2014), in this instance implementing BIM or not implementing BIM.

Cost benefit analysis is the process of comparing the net present value of benefits to the net present value of costs and to conduct an accurate cost-benefit analysis relevant agency guidelines should be adopted (Mike Fisher, 2012). The UAA Sports Arena project is in the purview of the University of Alaska Anchorage, which does not appear to have a formal CBA policy, so this project will rely upon foundational economic decision making to assist with completing this analysis.

Barry (2008) researched cost-benefit analysis, and provided a detailed guide to conducting general cost-benefit analysis (CBA). The research gives an outline of the processes involved in preforming a CBA, but does not provide all the tools. CBA sets out all the cost and benefits associated with a given project in monetary terms, which allows us to evaluate whether a project brings a net gain or not and allows the comparison of multiple options. This is particularly valuable when dealing with limited resources. A well-developed CBA can tell a decision maker generally what they need to know about a project, breaking down the relevant costs and benefits. A general technique to CBA starts with identifying the relevant costs and benefits to be measured, including resources, opportunity costs, costs over time, and do not include sunk costs.

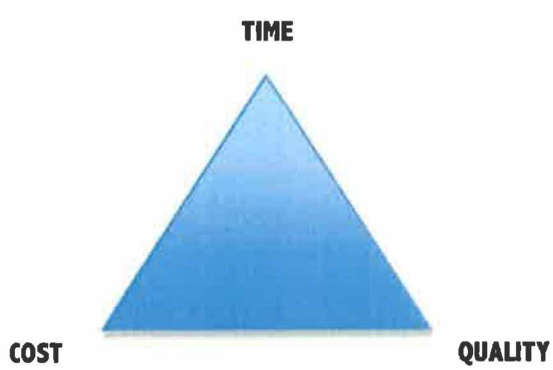
3.2 Cost Benefit Analysis Development

To conduct the CBA, a review of relevant literature was conducted to build an understanding of what the costs and benefits of BIM are (Table 3.1), and retrieve information that can be quantitatively applied to a completed construction project.

Table 3.1 BIM Potential Costs & Benefits

BIM Potential Costs & Benefits	
Costs	**Benefits**
Equipment	Improved communication
Software	Improved design
Training	Better data
Development	Improved customer service
Implementation	Less changes in scope
Legal	Better estimates
Human Error	Schedule reduction
Lack of Standardization	

It was determined that this project would review both cost and schedule data from the UAA Sports Arena project. Cost and schedule data are two critical parts in what is referred to as the project management triangle, Figure 3.1. A comprehensive review of all the project changes was conducted and sorted by both work package and project phase.



Singletary, S. (2010).
Figure 3.1 Project Management Cost-Quality-Time

A scenario was then developed in excel to evaluate the UAA Sports Arena base case, comparing what actually happened to what could have happened if BIM had been implemented on the project. The developed scenario was then input into @RISK and the results were then analyzed.

3.3 @RISK Scenario Analysis

@RISK performs risk analysis using Monte Carlo simulation to show possible outcomes based on the spreadsheet model and informs the user of how likely those outcomes are to occur. This was implemented into this research to assist with determining how likely BIM could have actually provided a benefit to the construction project management of the UAA Sports Arena project. @RISK was utilized on the analysis of both cost and schedule data.

3.4 Methodology Assumptions

Assumptions were made in the development of this research specifically in relation to the cost data acquired. Since the time of this research, the project was substantially complete as of August 1, 2014 and all the contracts and associated costs were not and will not be finalized. However, less than 1% of the project remains and would not have had a substantial impact on the analysis or the results. There still remains the 1 year warranty period so the project from an owner's perspective will not be complete until August 1, 2015. Regarding the evaluation of BIM impacts on schedule, all start dates are consider fixed and this report only speaks to level three of the schedule to allow for simplification of what is a complex critical path schedule developed in primavera. This simplification allows for ease of communication and interpretation.

Capital costs of BIM implementation are estimated to be between 1% and 5% of the total project budget based on the literature review. These percentages assumes all cost related to equipment procurement, licensing, and staff training and development. Finally the methodology assumes that the organization in this instance the University of Alaska Anchorage has no prior experience with BIM and would have been using it for the first time on the UAA Sports Arena project.

Chapter 4 Scenario Analysis

The following chapter serves to provide information specifically related to the UAA Sports Arena project, and provide analysis of costs specific to those areas of benefits that BIM contributes to construction project management such as clash detection, change orders, and schedule reduction. This chapter will provide basic information regarding the UAA Sports Arena project, information on how the project was managed, discuss how clash detection was performed, and conclude with a review of project changes.

4.1 UAA Sports Arena Project Information

The new sports arena constructed specifically for the University of Alaska Anchorage, was substantially completed August 1, 2014 and is currently named the Alaska Airlines Center, is a 197,000 SQFT facility built in support of education, athletics, and the community. The total project cost for the UAA sports arena was $110.5 million dollars. The new arena included an approximately 5,000 seat performance gymnasium, approximately 500 seat auxiliary gymnasium, a gymnastics training facility, a student athlete strength and conditioning gym, a public recreation facility, a sports medicine department featuring a hydrotherapy pool, 19 lockers for sports, visitors, and the public, a balcony level running track, luxury box seating, and a restaurant. In addition to the facility itself, the area has onsite parking for approximately 600, and to assist with traffic management, a new roundabout was constructed on a major road adjacent to the property.

4.2 UAA Sports Arena Project Management

This section provides a general overview of how the UAA Sports Arena project was managed; this is not comprehensive but helps to provide some insight into how the budgets were developed and maintained and how activities that BIM can significantly impact were conducted.

The contract delivery method utilized to manage the project is referred to as construction manager at risk. It is a method utilized to bring a general contractor onto the project team as a construction consultant during the design phase providing their professional expertise to the design team assisting with developing the project documents to approximately 60% completion, at which point they are allowed to bid on the remainder providing a guaranteed maximum price (GMP). Through this method, the project team was able to develop the project to an initial project budget of \$109 million dollars; roughly in January of 2014, a restaurant was added to the contractor's scope of work increasing the value of the project by \$1.5 million for a total project budget of \$110.5 million dollars.

Outside of the above contract delivery method, the remainder of the project was managed off of 2D drawings and specifications which outlined what scope of work was to be completed and how. There was a 3D model developed and utilized by the design team, but it was not used specifically for construction project management or by the general contractor. The only exception was with regards to the structural steel, for which a Revit model was developed and the entire team constantly reviewed through the steel fabrication in order to make sure everything arrived correctly since in Alaska we do not have the capability to fabricate our own steel.

4.3 UAA Sports Arena Clash Detection

Clash detection is the process of reviewing the project design with each of the trades who will require space in the ceiling, walls, or other areas to ensure there are no conflicts such as electrical conduit running through the center of an air supply duct. This is an incredibly important exercise to perform prior to actual installation as it prevents conflicts in the field, reduces errors, and assist with efficient space utilization.

Traditionally, clash detection is performed in a room with all the trades involved and any other relevant project team members who sit down with a 2D set of drawings and negotiate for space, making sure that they can complete their scope of work as designed and in accordance with all relevant building codes. This traditional approach to clash detection is time consuming and costly, and is precisely how clash detection was performed on the UAA Sport Arena project.

As noted in the literature review and case studies, BIM can greatly improve on the ability to conduct clash detection. With every building component represented, it is more efficient to utilize a designer to coordinate all the space requirement for each trade as opposed to a room full of trade professional negotiating over space. The developed model can then provide shop drawings that show exactly where the materials should be installed and at what elevations. This saves planning time and lends itself to a more efficient installation, based on the literature review clash detection can save up to 10% of the total construction cost.

4.4 UAA Sports Arena Change Orders

Scope change can be a design error or omission, an owner directive, and even an unforeseen condition such as unanticipated contaminated soils change. The UAA Sports Arena project had multiple project changes which accounted for 9.15% of the construction budget please refer to Table 4.1 and Figure 4.1. For a detailed breakdown of project budget and contract changes, please refer to the appendix.

Table 4.1 Modification Table

MODIFICATION/DESCRIPTION	AMOUNT	PERCENT OF CONTRACT
General Conditions	**$ 562,567**	0.62%
Site Work	**$ 972,925**	1.08%
Concrete	**$ 425,565**	0.47%
Metals	**$ 2,340,401**	2.60%
Carpentry	**$ 374,760**	0.42%
Doors, Windows & Glass	**$ 143,099**	0.16%
Finishes	**$ 198,767**	0.22%
Furnishings	**$ 95,621**	0.11%
Conveying Equipment	**$ 403,422**	0.45%
Mechanical	**$ 1,270,691**	1.41%
Electrical	**$ 954,028**	1.06%
Audio/Visual	**$ 163,834**	0.18%
Other	**$ 331,769**	0.37%
Total Change Order Cost	**$ 8,237,448**	9.15%
Total Number of Change Orders	227	
Average Cost per Change Order	$ 36,288.32	
Construction Budget	$ 90,054,641.00	

Table 4.1 displays the total change orders by division/specialty of the project. These are the total values of the changes in scope as it occurred on the UAA Sports Arena project, and for clarity a bar chart has been developed based upon Table 4.1, which clearly articulates which areas of the project had the largest change in scope.

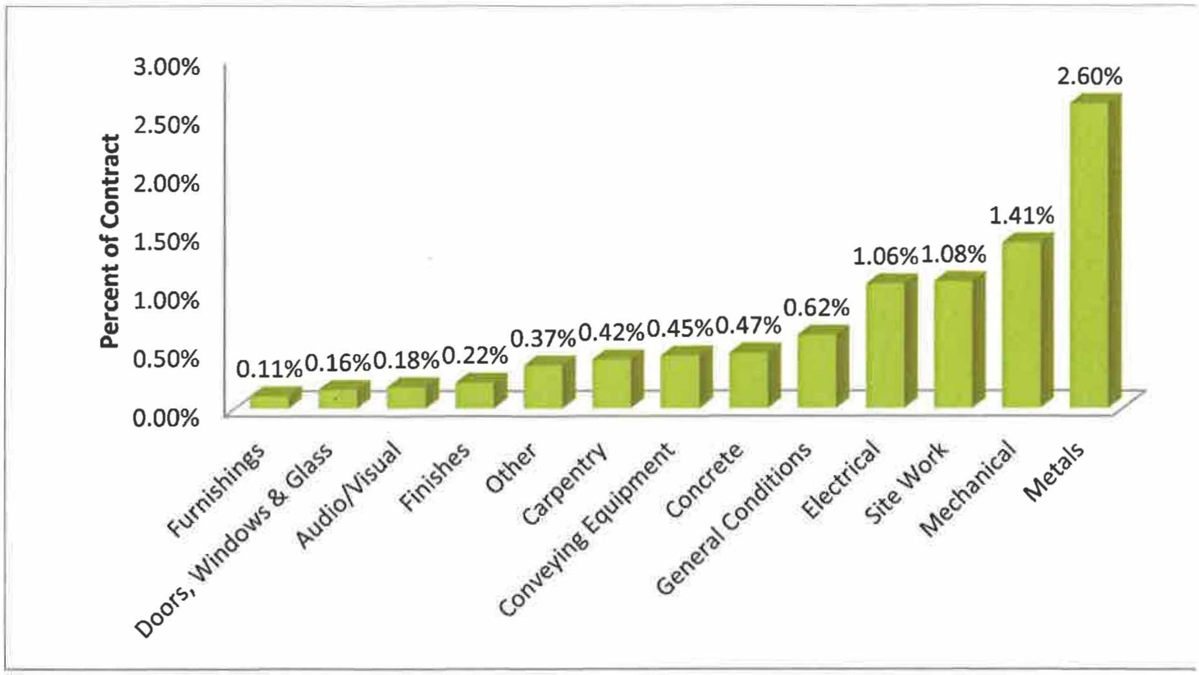


Figure 4.1 Change Orders as a % of Base Construction Contract

The largest areas of change were in the metals category, which includes items such as structural steel. The other large areas of change were in the mechanical systems, site work, and electrical systems. The changes above include the addition of the restaurant that was added to the contractor's scope of work in 2014.

As noted in the literature review, BIM assists with reducing changes on a project through modeling and constructability reviews allowing errors and omissions to be located prior to construction during the design and planning phases of a construction project. This can result in a project saving of 0% to 40% of the total change orders.

Chapter 5 Model, Analysis, Results

Based on the literature review and the project cost data collected, a model was developed to analyze the costs and benefits of BIM on the UAA Sports Arena project. This model combines two techniques specific to engineering management, economic decision making, and cost estimating. Two separate evaluations were conducted, first a review of schedule implications and second, a review of cost implications. This chapter covers scenario analysis based on schedule, cost, and provides results.

5.1 Scenario Analysis Based on Schedule

To consider the impact implementation of BIM could have had on schedule, a complex CPM schedule managed from a construction manager at risk contract delivery method needed to be compressed into a manageable format. As outlined in the methodology assumptions, this work breakdown structure was compressed to level three and placed into an excel model for input into @RISK. The following chart is the work breakdown structure based on how the work was scheduled, which was by building feature as opposed to billable work package.

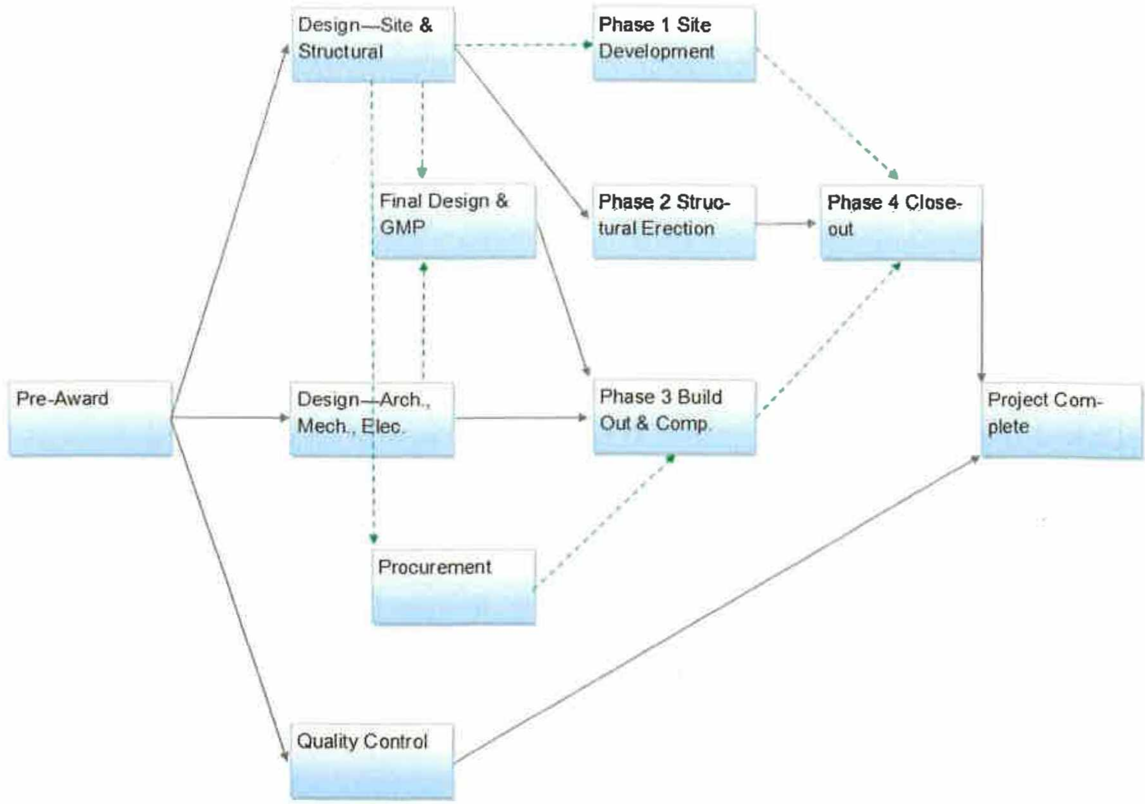


Figure 5.1 UAA Sports Arena Process Flow Diagram

Figure 5.1 shows the sequence of activities. The green dashed lines are concurrent activities. As noted above, the project was managed via construction manager at risk which in some ways operates as a design build which results in numerous concurrent activities, and provides for a lot of flexibility within the project schedule.

For estimating the impact implementing BIM could have had on the UAA Sports arena, similar to cost, it was assumed that change could have either not been reduced or was completely reduced. To estimate the total change to each individual work package, each change order had to be individually reviewed and sorted into the correct schedule item based on professional experience with the project. This allowed for representation of the total impact those cumulative changes had to the various phases of work. This information is summarized in Table 5.1.

Table 5.1 BIM Schedule Based Efficiency Gains & Losses

WBS	Name	Start	Finish	Duration	% Change
1	**UAA Sports Arena**	**10/10/2011**	**8/1/2014**	**735**	
1.1	Pre-Award	10/10/2011	1/20/2012	75	**0%**
1.2	**Pre-Construction Services**	**1/23/2012**	**2/27/2013**	**288**	
1.2.1	Design - Site & Structural	1/23/2012	12/6/2012	229	**7%**
1.2.2	Design - Arch., Mech., Elec.,	1/23/2012	2/27/2013	288	**7%**
1.2.3	Final Design & GMP	8/27/2012	11/29/2012	69	**7%**
1.3	**Construction Services**	**1/23/2012**	**8/1/2014**	**660**	
1.3.1	Quality Control	1/23/2012	8/1/2014	660	**0%**
1.3.2	Procurement	7/2/2012	3/2/2014	436	**0%**
1.3.3	Phase 1 Site Development	4/16/2012	6/30/2014	576	**2%**
1.3.4	Phase 2 Structural Erection	8/13/2012	9/11/2013	283	**3%**
1.3.5	Phase 3 Build Out & Completion	2/7/2013	6/9/2014	348	**4%**
1.3.6	Phase 4 Commissioning & Closeout	5/5/2014	8/1/2014	65	**10%**
1.3.7	Project Completion	8/1/2014	8/1/2014	0	

Reviewing Table 5.1, the start and finish dates are the actual dates of the UAA Sports Arena project, and the efficiency gains and losses are highlighted green and red respectively. In addition to assuming possible gain in efficiency as previously noted the use of BIM results in a loss of efficiency during the design and planning phases of a project. This is especially true when the company has no direct experience such as the University of Alaska Anchorage. The impacts of this loss in efficiency are accounted for in Table 5.1 as well as the potential savings. This information was then input into @RISK which provided the following charts.

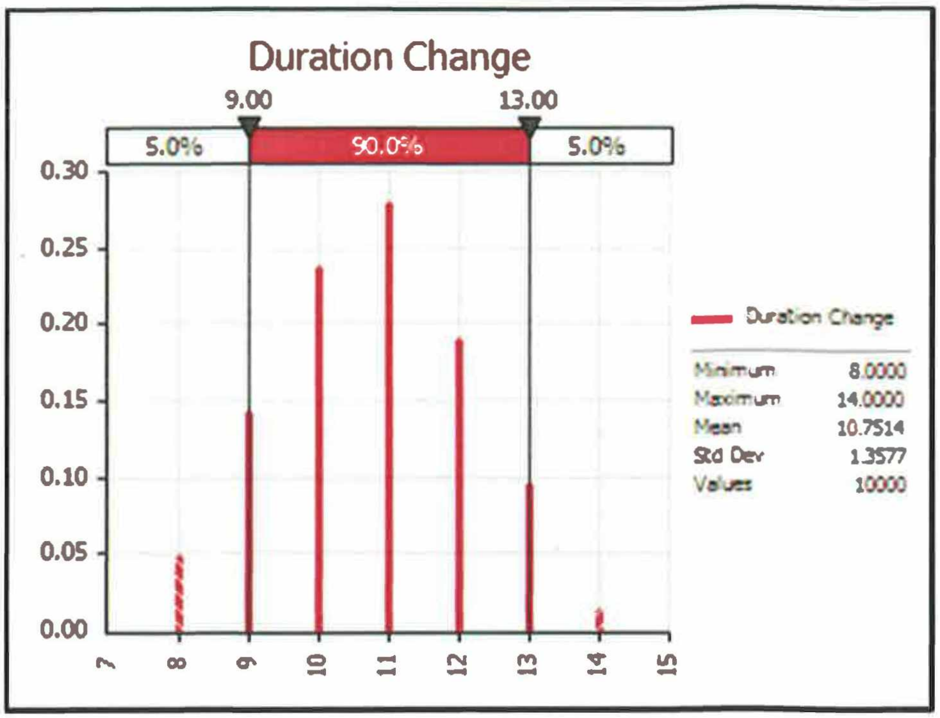


Figure 5.2 BIM Estimated Change in Project Duration

The above chart reflects an estimated total project duration reduction of 10.75 days, based on efficacy gains from using BIM to assist with construction management of the UAA Sports Arena project. Also considered were the cost impacts in relation to a reduction in total project schedule. These are referred in Figure 5.3.

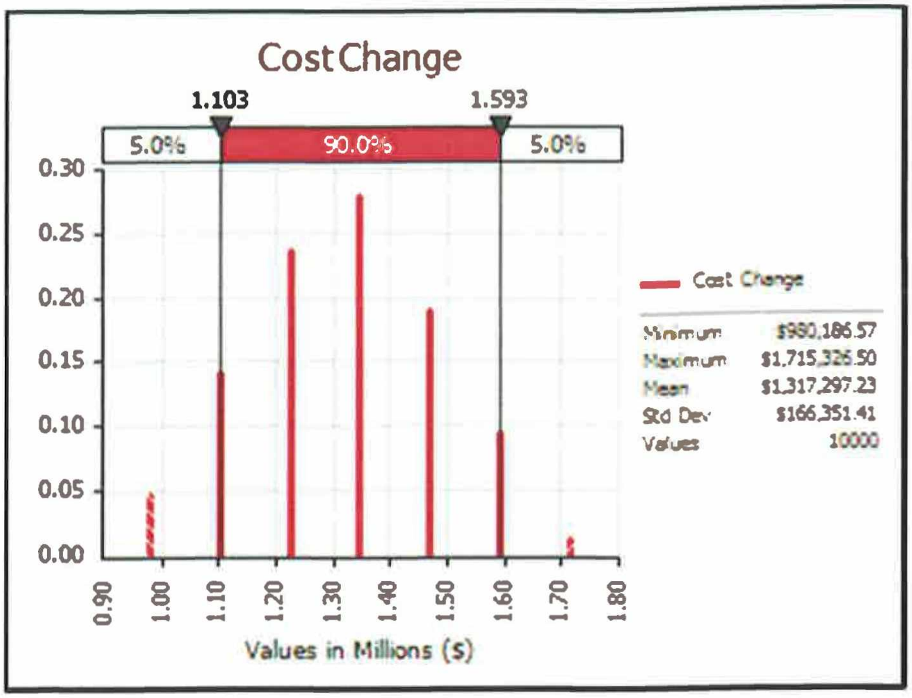


Figure 5.3 BIM Estimated Change in Project Duration (Cost)

The above calculation is relative to the change in duration shown in Figure 5.5. What this accounts for is a daily construction cost which is commonly referred to as a "burn rate" for the entire cost of construction of $122,000 per day. Application of the daily burn rate results in a mean project savings of $1.32 million based on the 11 day reduction in total project schedule.

In addition to reviewing the outputs of the model as reflected in the charts above, this information was input back into the project schedule to determine what the estimated completion date could have been based on the projected efficiency gains from implementing BIM. Please refer to Table 5.4 below.

Table 5.2 UAA Sports Arena Revised Schedule

WBS	Name	Start	Finish	Duration
1	**UAA Sports Arena**	**10/10/2011**	**7/17/2014**	**724**
1.1	Pre-Award	10/10/2011	1/20/2012	75
1.2	**Pre-Construction Services**	**1/23/2012**	**3/14/2013**	**298**
1.2.1	Design - Site & Structural	1/23/2012	12/19/2012	237
1.2.2	Design - Arch., Mech., Elec.,	1/23/2012	3/14/2013	298
1.2.3	Final Design & GMP	8/27/2012	12/4/2012	71
1.3	**Construction Services**	**1/23/2012**	**7/17/2014**	**649**
1.3.1	Quality Control	1/23/2012	7/17/2014	649
1.3.2	Procurement	7/2/2012	2/24/2014	436
1.3.3	Phase 1 Site Development	4/16/2012	6/24/2014	572
1.3.4	Phase 2 Structural Erection	8/13/2012	9/5/2013	279
1.3.5	Phase 3 Build Out & Completion	2/7/2013	5/29/2014	340
1.3.6	Phase 4 Commissioning & Closeout	4/23/2014	7/17/2014	62
1.3.7	Project Completion		7/17/2014	

As reflected in Table 5.2 as opposed to completing the project on August 1, 2014, the project could have been completed on July 17, 2014 based on the 11 day estimated duration reduction. These savings are reflected in Figure 5.4, which is a revised version of the WBS showing the change in days per activity. Due to how the project managed allowing for design work to be complete concurrently with construction activities, increases in duration to the design activities had no significant impact on the project schedule, while gains realized in the work performed had a substantial impact.

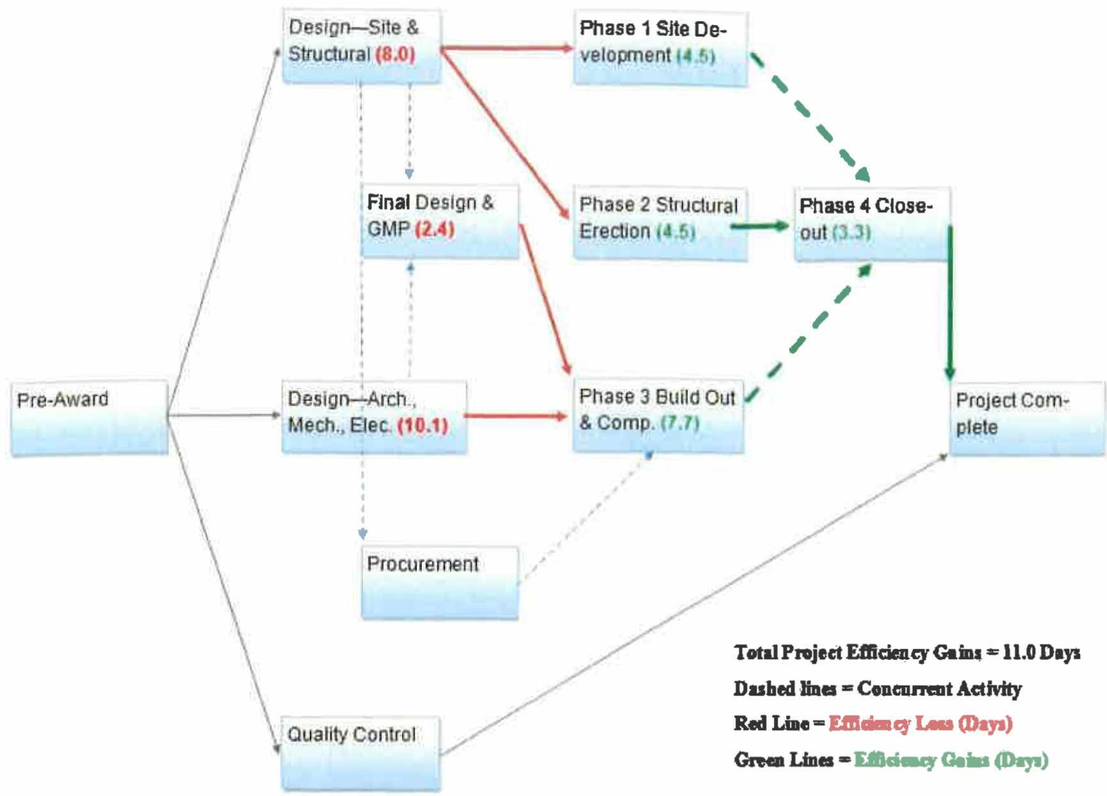


Figure 5.4 UAA Process Flow Chart Revised

5.2 Scenario Analysis Based on Cost

To begin, the evaluation of the effect BIM implementation could have had on the UAA Sports Arena project, all project cost data including bases construction costs, project management costs, architect & engineering costs, and change order costs had to be gathered and organized into a usable format. Figure 5.5 reflects how the costs of the project were broken down into separate divisions based on CSI master format, which account for the various scopes of work that compromises the total construction budget of the UAA Sports Arena project.

Figure 5.5 Cost Breakdown Structure

Table 5.5 provides a more detailed breakdown of the information above showing base construction cost, change order costs, and then final total cost. This allows for analysis of the total project change within each of the individual project work packages.

Table 5.3 UAA Sports Arena Project Budget

Total Project Budget	**$ 110,585,000**		
Project Management / A&E	**$ 20,530,359**		
Total Construction Budget	**$ 90,054,641**		
Budget by Division	**Base Cost**	**Total Change**	**Total Cost**
Div. 1 General Conditions	$ 15,392,821	$ 562,567	$15,955,388
Div. 2 Site work	$ 5,385,934	$ 972,925	$ 6,358,859
Div. 3 Concrete	$ 7,803,483	$ 425,565	$ 8,229,048
Div. 4 Masonry	$ 62,040	$ -	$ 62,040
Div. 5 Metals	$ 9,559,459	$ 2,340,401	$11,899,860
Div. 6 Carpentry	$ 616,865	$ 374,760	$ 991,625
Div. 7 Moisture - Thermal Control	$ 3,132,823	$ -	$ 3,132,823
Div. 8 Doors, Windows & Glass	$ 1,001,662	$ 143,099	$ 1,144,761
Div. 9 Finishes	$ 7,891,706	$ 198,767	$ 8,090,473
Div. 10 Specialties	$ 276,322	$ 331,769	$ 608,091
Div. 11 Equipment	$ 430,072	$ -	$ 430,072
Div. 12 Furnishing	$ 1,259,555	$ 95,621	$ 1,355,176
Div. 13 Special Construction	$ -	$ -	$ -
Div. 14 Conveying Equipment	$ 552,344	$ 403,422	$ 955,766
Div. 15 Mechanical	$ 15,387,545	$ 1,270,691	$16,658,236
Div. 16 Electrical	$ 10,681,000	$ 954,028	$11,635,028
Div. 17 Audio / Visual	$ 2,383,562	$ 163,834	$ 2,547,396
Sub Totals	$ 81,817,193	$ 8,237,448	$90,054,641

To develop Table 5.3, a comparison was created between the base contract total and current project totals. The comparison included the review of 227 change orders that had to be sorted based on professional experience in their respective divisions. This information provides the total amount of change in scope that occurred during the construction of the UAA Sports Arena project. Based on the literature review, it was found that reductions in cost from BIM implementation are based on efficacy gains from streamlined communication, and early detection of design errors. Clash detection done in advance by the design team would have allowed field professionals more time to allocate towards actually completing the work. These are the kinds of changes that are reflected in the potential cost savings in Table 5.3.

For estimating what kind of affect this could have had on the UAA Sports Arena project, it is assumed that BIM could have either had no impact on the total change in scope, or completely eliminated the change in scope by providing a possible range of potential efficiency gains resulting from the implementation of BIM. In addition to efficiency gains, there are also efficiency losses due to UAA having no prior experience with BIM and would have been required to procure equipment, software, training, and simply learn the new system. The following table reflects the ranges of these assumptions as a dollar amount.

Table 5.4 BIM Cost Based Efficiency Gains & Losses

BIM Costs	**$ 205,304**	**$ 5,529,250**
	BIM Savings	
Budget by Division	**Class Detection / CO Reduction**	
Div. 1 General Conditions	$ -	$ 562,567
Div. 2 Site work	$ -	$ 972,925
Div. 3 Concrete	$ -	$ 425,565
Div. 4 Masonry	$ -	$ -
Div. 5 Metals	$ -	$ 2,340,401
Div. 6 Carpentry	$ -	$ 374,760
Div. 7 Moisture - Thermal Control	$ -	$ -
Div. 8 Doors, Windows & Glass	$ -	$ 143,099
Div. 9 Finishes	$ -	$ 198,767
Div. 10 Specialties	$ -	$ 331,769
Div. 11 Equipment	$ -	$ -
Div. 12 Furnishing	$ -	$ 95,621
Div. 13 Special Construction	$ -	$ -
Div. 14 Conveying Equipment	$ -	$ 403,422
Div. 15 Mechanical	$ -	$ 1,270,691
Div. 16 Electrical	$ -	$ 954,028
Div. 17 Audio / Visual	$ -	$ 163,834

In Table 5.4, efficiency losses are calculated as a percent of total project cost based on the literature review from 1% to 5%. Efficiency gains are within each of the individual work packages reflecting either no reduction of change or a complete reduction in change. The above information was then entered into @RISK which provided the following charts. Complete set of model output information can be referenced in the appendix.

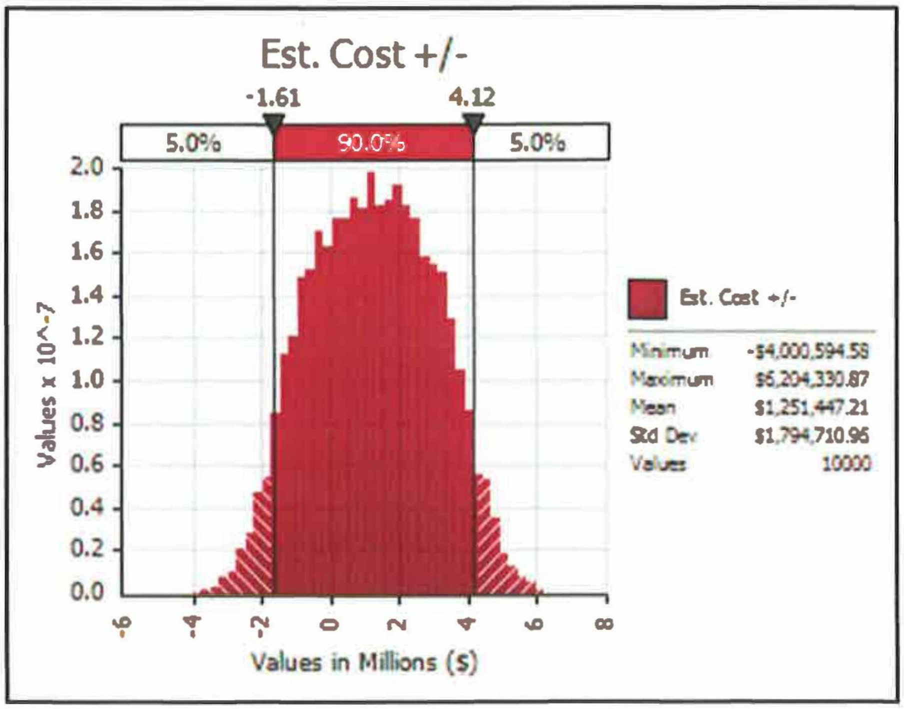


Figure 5.6 BIM Estimated Impact on Cost

Based on Figure 5.6, BIM has a mean savings of $1.25 million. Additional information contained in the summary statistics is the mode savings were projected to be $1.24 million in savings. Another output generated from @RISK is a breakeven chart (Figure 5.7), with the estimated cost savings set at zero. The simulation estimated a

72.8% chance that the project would have a cost savings, which would have resulted from the benefits of BIM outweighing the costs.

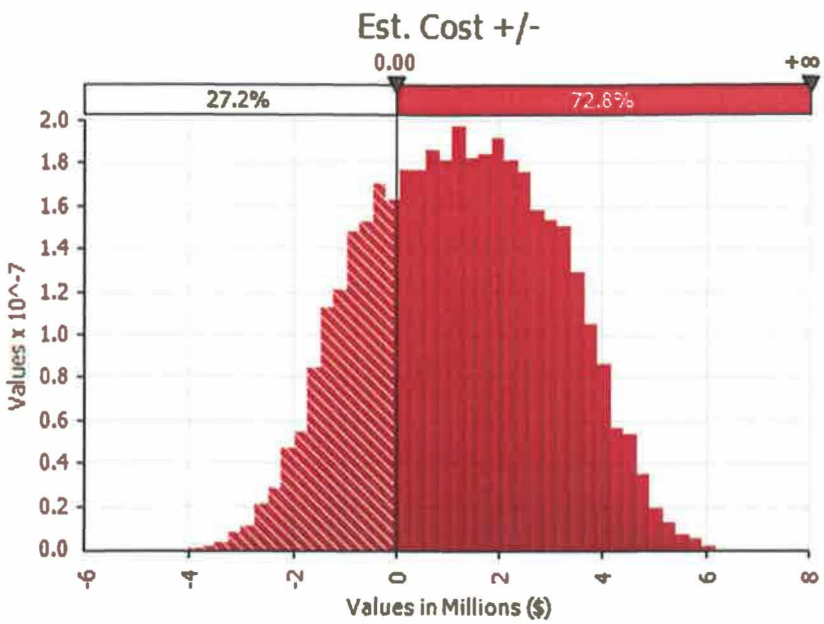


Figure 5.7 BIM Break Even Chart

5.3 Results

This research found the cost and benefits of implementing BIM and then conducted a scenario analysis using data from the UAA Sports Arena project. Research overwhelming measured the benefit of BIM to construction project management as a percentage of total cost. Applying this method as outlined in section 5.1, the impacts of implementing BIM on the UAA Sports Arena project most likely would have resulted in a reduction in total project schedule estimated to be at 11 days which results in a total project savings of $1.35 million or 1.5% of the total project budget. This is well within the up to 7% in savings reflected in the literature review and resulting from efficiency gained in the project schedule.

As outlined in section 5.2 scenario analyses based on construction cost resulted in an estimated project savings of $1.24 million, this amounts to a 1.1% total project savings which is representative of the other projects realizing savings through BIM. It was estimated that if BIM was in-fact implemented on the UAA Sports Arena project, UAA would have had a 72.8% chance of realizing a positive benefit. These savings are the result of gains in efficiency through more efficient document control, communication, design error detection, and efficient labor distribution which perhaps would be better reflected in the project schedule.

Chapter Six Conclusions and Future Work

The following chapter summarizes this research conclusions and recommendations for future work in the area of BIM and construction project management.

BIM is an innovative tool showing positive results with the data showing an ever increasing adoption rate by private industry, and a push by government agencies for incorporation into how they conduct business. Based on the CBA and scenario analysis conducted in this research, the benefits of BIM are clearly quantifiable and follow the trend of data and research that is being produced in support of BIM. Based on the results of this research conducted through the evaluation of project data relative to cost and schedule, it is recommended that the University of Alaska Anchorage look closely at implementing BIM as a tool in support of construction project management.

This research project is limited in scope in its application of costs and benefits to only the construction phase of the UAA Sports Arena project and excluded product lifecycle management. This work should be expanded upon to include more projects throughout the state of Alaska to provide more comprehensive information and better support to make an informed decision on whether or not to implement BIM.

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Appendix A. Project Budget

Project Budget - October 26th 2014		
Division	**Description**	**Budget**
1	GC Reimbursable Costs	$ 5,942,147.00
1	GC Lump Sum Contract	$ 6,897,464.00
	Reimbursable Allowances	$ 1,068,879.00
2	Site Work	$ 5,385,934.00
3	Concrete	$ 7,803,483.00
4	Masonry	$ 62,040.00
5	Metals	$ 9,559,459.00
6	Carpentry	$ 616,865.00
7	Moisture - Thermal Control	$ 3,132,823.00
8	Doors, Windows & Glass	$ 1,001,662.00
9	Finishes	$ 7,891,706.00
10	Specialties	$ 276,322.00
11	Equipment	$ 430,072.00
12	Furnishings	$ 1,259,555.00
13	Special Construction	$ -
14	Conveying Equipment	$ 552,344.00
15	Mechanical	$ 15,387,545.00
16	Electrical	$ 10,681,000.00
17	Audio/Visual	$ 2,383,562.00
	Contractors Fee	$ 1,484,331.00
	BASE CONTRACT AMOUNT	**$ 81,817,193.00**
Modification	**Description**	**Amount**
1	Value Engineering	$ -
2	See Modifications Summary Tab	$ 415,174.00
3	See Modifications Summary Tab	$ 704,329.00
4	See Modifications Summary Tab	$ 1,350,489.00
5	Phase 2 of Construction	$ -
6	See Modifications Summary Tab	$ 383,707.00
7	See Modifications Summary Tab	$ 60,703.00
8	Contract Adjustment	$ -
9	See Modifications Summary Tab	$ 421,522.00

10	See Modifications Summary Tab	$ 482,843.00
11	See Modifications Summary Tab	$ 204,474.00
12	A/V Credits	$ -
13	See Modifications Summary Tab	$ 73,168.00
14	See Modifications Summary Tab	$ 145,097.00
15	See Modifications Summary Tab	$ 697,995.00
16	Credits	$ -
17	See Modifications Summary Tab	$ 271,464.00
18	See Modifications Summary Tab	$ 114,368.00
19	Credits	$ -
20	See Modifications Summary Tab	$ 163,175.00
21	See Modifications Summary Tab	$ 213,855.00
22	See Modifications Summary Tab	$ 272,938.00
23	Credits	$ -
24	See Modifications Summary Tab	$ 121,615.00
25	See Modifications Summary Tab	$ 1,425,000.00
26	See Modifications Summary Tab	$ 70,128.00
27	See Modifications Summary Tab	$ 81,881.00
28	Credits	$ -
29	See Modifications Summary Tab	$ 53,355.00
30	See Modifications Summary Tab	$ 355,967.00
31	See Modifications Summary Tab	$ 154,201.00
	Modification Total	**$ 8,237,448.00**
	TOTAL CONSTRUCTION CONTRACT	**$ 90,054,641.00**
	Owner, A/E, Other Project Costs	$ 20,530,359.00
	TOTAL PROJECT COST	**$ 110,585,000.00**

Appendix B. Contract Modifications Summary

ITEM	MODIFICATION/DESCRIPTION	AMOUNT	MASTER FORMAT DIVISION	
	Modification Number 2	**$ 415,174.00**		
1	Incorporated Hydrotherapy Tub	$ 176,369.00	15	Mechanical
2	Structural Steel Detailing	$ 31,604.00	5	Metals
3	Subsurface Investigations	$ 52,441.00	2	Site Work
4	A/V Infrastructure Add	$ 154,760.00	17	Audio/Visual
	Modification Number 3	**$ 704,329.00**		
1	Remove and backfill Soil	$ 17,654.00	2	Site Work
2	Add Trap Primers per MOA	$ 6,323.00	15	Mechanical
3	Structural Revisions per MOA	$ 284,667.00	5	Metals
4	Add Floor Sinks	$ 4,671.00	15	Mechanical
5	Structural Steel Changes	$ 100,274.00	5	Metals
6	Plumbing Revisions	$ 1,448.00	15	Mechanical
7	Floor Grates	$ 3,071.00	12	Furnishings
8	Paperwork Correction	$ 201,878.00	1	General Conditions
9	Cooling well work	$ 84,343.00	15	Mechanical
10	Contract language adjustment	$ -	1	General Conditions
	Modification Number 4	**$ 1,350,489.00**		
1	MOA Fencing	$ 58,971.00	2	Site Work
2	MOA Planting	$ 73,583.00	2	Site Work
3	Replace Manhole	$ 11,972.00	15	Mechanical
4	Structural Modification	$ 1,217.00	5	Metals
5	Steel Modification	$ 2,162.00	5	Metals
6	Steel Modification	$ 3,688.00	5	Metals
7	Rain Leader Relocation	$ 7,699.00	15	Mechanical
8	Modify Grading	$ 2,562.00	2	Site Work
9	Steel Modification	$ 1,146,453.00	5	Metals
10	Steel Modification	$ 42,182.00	5	Metals
	Modification Number 5			
1	Phase 2 - Incorporated		1	General Conditions
	Modification Number 6	**$ 383,707.00**		
1	Structural Steel Modification	$ 191,853.50	5	Metals
2	Concrete Modification	$ 191,853.50	3	Concrete
	Modification Number 7	**$ 60,703.00**		
1	Unknown	$ 60,703.00		

	Modification Number 8	**$ -**		
1	Contact Adjustment	$ -	1	General Conditions
	Modification Number 9	**$ 421,522.00**		
1	Modify Pull Box	$ 67,259.00	16	Electrical
2	Steel Modification	$ 17,923.00	5	Metals
3	Block outs	$ 4,739.00	6	Carpentry
4	Electrical Rough-In	$ 11,688.00	16	Electrical
5	Steel Modification	$ 1,588.00	5	Metals
6	Site Signage	$ 7,568.00	2	Site Work
7	Steel Modification	$ 107,255.00	5	Metals
8	Stair Modification	$ 909.00	5	Metals
9	Steel Modification	$ 6,873.00	5	Metals
10	Steel Modification	$ 43,286.00	5	Metals
11	Seating Connections	$ 25,301.00	5	Metals
12	Electrical Rough-In	$ 1,413.00	16	Electrical
13	Steel Framing for Elevator	$ 5,212.00	5	Metals
14	Steel Details	$ 31,670.00	5	Metals
15	Steel Beam Mod.	$ 3,700.00	5	Metals
16	HD Scoreboard	$ 83,860.00	16	Electrical
17	Added Rebar	$ 1,278.00	3	Concrete
	Modification Number 10	**$ 482,843.00**		
1	Add. Alternates (Seats Etc..)	$ 267,725.00		
2	Plunge Tank Modification	$ 5,379.00	15	Mechanical
3	Additional Wall Openings	$ 2,982.00	6	Carpentry
4	Footing Modifications	$ 1,172.00	3	Concrete
5	Slab depression for freezer	$ 1,533.00	3	Concrete
6	Additional metal decking	$ 18,202.00	5	Metals
7	Provide bracing for backfill	$ 117,062.00	2	Site Work
8	Mech. Penetrations	$ 1,541.00	15	Mechanical
9	Pre-cast Riser Modifications	$ 67,247.00	3	Concrete
	Modification Number 11	**$ 204,474.00**		
1	Contract language adjustment	$ -	1	General Conditions
2	Schedule Delay Adjustment	$ -	1	General Conditions
3	Footing Modifications	$ 15,355.00	3	Concrete
4	Volleyball Inserts	$ 2,655.00	3	Concrete
5	Phase 2 - Conformed Changes	$ 99,044.00	1	General Conditions
6	Valve additions	$ 36,106.00	15	Mechanical
7	Added Rebar	$ 2,486.00	3	Concrete
8	Shoring	$ 2,910.00	3	Concrete
9	Steel modification	$ 5,074.00	5	Metals

10	Blocking	$ 6,594.00	6	Carpentry
11	Modify framing	$ 1,337.00	6	Carpentry
12	Add furring	$ 23,545.00	6	Carpentry
13	Slab reinforcement	$ 1,861.00	3	Concrete
14	Plumbing Revisions	$ 7,507.00	15	Mechanical
	Modification Number 12	**$ (343,080.00)**		
1	A/V Credit	$ (318,303.00)	17	Audio/Visual
2	FCU Credit	$ (3,172.00)	15	Mechanical
3	Wall Revision	$ (1,366.00)	6	Carpentry
4	Delete Soda Dispensers	$ (20,239.00)	11	Equipment
	Modification Number 13	**$ 73,168.00**		
1	Door Hardware Changes	$ 22,347.00	8	Doors, Windows & Glass
2	Backflow Preventer	$ 7,018.00	15	Mechanical
3	Re-Lite Windows (Doors)	$ 10,092.00	8	Doors, Windows & Glass
4	Sound Bats	$ 30,370.00	6	Carpentry
5	Add Alt.	$ 3,341.00		
	Modification Number 14	**$ 145,097.00**		
1	Modify Elec. Requirements	$ 80,955.00	16	Electrical
2	Provide Temp. Bike Path	$ 7,838.00	2	Site Work
3	Final Steel Reconciliation	$ 56,304.00	5	Metals
	Modification Number 15	**$ 697,995.00**		
1	Column baseplate modification	$ 11,231.00	5	Metals
2	Modify slab edges	$ 83,209.00	3	Concrete
3	Steel gussets welding	$ 1,166.00	5	Metals
4	Dewatering system	$ 33,908.00	15	Mechanical
5	Beam movement	$ 535.00	5	Metals
6	Steel railings	$ 41,827.00	5	Metals
7	Modify coiling doors	$ 5,714.00	8	Doors, Windows & Glass
8	Modify Elmore roundabout	$ 428,898.00	2	Site Work
9	Gym center curtain wire	$ 32,153.00	5	Metals
10	Modify electrical panel	$ 2,825.00	16	Electrical
11	Added metal stud backing	$ 1,646.00	6	Carpentry
12	Modify OH door support	$ 556.00	5	Metals
13	Modify Structural Steel	$ 6,387.00	5	Metals
14	Modify Door	$ 10,472.00	8	Doors, Windows & Glass
15	Provide Access Control System	$ 37,468.00	16	Electrical
	Modification Number 16	**$ (618,103.00)**		
1	Credit Sub Buyout	$ (600,000.00)	1	General Conditions
2	Delete Cup Holders	$ (8,620.00)	12	Furnishings
3	Delete Fire Taping	$ (9,483.00)	6	Carpentry

	Modification Number 17	**$ 271,464.00**		
1	Slab water proofing	$ 22,164.00	3	Concrete
2	Add dryer exhaust fan	$ 9,008.00	15	Mechanical
3	Add steel supports	$ 69,582.00	5	Metals
4	Modify elevator door and support	$ 3,799.00	5	Metals
5	Relocate ductwork	$ 4,580.00	15	Mechanical
6	Add boulders to site	$ 8,450.00	2	Site Work
7	Add return air	$ 10,450.00	15	Mechanical
8	Modify locker room ceilings	$ 9,487.00	6	Carpentry
9	Provide fire treated plywood	$ 24,116.00	6	Carpentry
10	Add makeup mirror power	$ 9,499.00	16	Electrical
11	Wall Revision	$ 744.00	6	Carpentry
12	Modify return air opening	$ 1,581.00	15	Mechanical
13	Add conduit & fire alarm connectors	$ 10,493.00	16	Electrical
14	Dishwasher electrical changes	$ 1,259.00	16	Electrical
15	Provide 40 amp boot dryer breakers	$ 1,279.00	16	Electrical
16	Asphalt revisions	$ 84,973.00	2	Site Work
	Modification Number 18	**$ 114,368.00**		
1	Access control panels	$ 9,788.00	16	Electrical
2	Add fan controller	$ 3,567.00	15	Mechanical
3	Modify gymnastics pit	$ 1,895.00	3	Concrete
4	Add framing behind liner panels	$ 16,606.00	6	Carpentry
5	Add level 1 flooring	$ 3,614.00	9	Finishes
6	Add HM door frame and hardware	$ 5,440.00	8	Doors, Windows & Glass
7	Electrical modifications	$ 9,926.00	16	Electrical
8	Add well pump	$ 62,080.00	15	Mechanical
9	Steel addition	$ 1,452.00	5	Metals
	Modification Number 19	**$ (121,525.00)**		
1	Delete relief fan	$ (4,969.00)	15	Mechanical
2	Delete J-box connections	$ (592.00)	16	Electrical
3	Delete operable glass partitions	$ (13,964.00)	8	Doors, Windows & Glass
4	Delete 3rd party commissioning	$ (102,000.00)	1	General Conditions
	Modification Number 20	**$ 163,175.00**		
1	Elevator addition	$ 163,175.00	14	Conveying Equipment
	Modification Number 21	**$ 213,855.00**		
1	Washed drain rock and pipe wrap	$ 62,092.00	2	Site Work
2	Pre-cast modifications	$ 13,522.00	3	Concrete
3	Electrical rough-in for Totem	$ 32,799.00	16	Electrical
4	Steel in-fill for floor	$ 1,162.00	5	Metals
5	Add receptacles	$ 2,341.00	16	Electrical

6	Add valves	$ 21,294.00	15	Mechanical
7	Add comm. Outlets	$ 6,247.00	16	Electrical
8	Add sprinkler heads	$ 5,027.00	15	Mechanical
9	Adjust roller shades sequence	$ 2,432.00	16	Electrical
10	Add knife plates for banners	$ 5,477.00	5	Metals
11	Add return air grills	$ 3,879.00	15	Mechanical
12	Provide electrical connections	$ 14,473.00	16	Electrical
13	Pipe heating and cooling coils	$ 22,709.00	15	Mechanical
14	Elevator pit lighting	$ 3,358.00	16	Electrical
15	Add soffit & ceiling	$ 2,491.00	6	Carpentry
16	Provide 2 hour fire rated shaft	$ 14,552.00	6	Carpentry
	Modification Number 22	**$ 272,938.00**		
1	Provide extra site material	$ 44,730.00	2	Site Work
2	Add GWB	$ 2,303.00	6	Carpentry
3	provide sump level sensor	$ 3,938.00	15	Mechanical
4	Add radius to curb	$ 3,418.00	2	Site Work
5	Modify handrail returns	$ 11,699.00	6	Carpentry
6	Add second passenger elevator	$ 206,850.00	14	Conveying Equipment
	Modification Number 23	**$ -**		
1	No Cost Mod	$ -	1	General Conditions
	Modification Number 24	**$ 121,615.00**		
1	Room mechanical reconfiguration	$ 77,585.00	15	Mechanical
2	Control wiring	$ 13,032.00	16	Electrical
3	Additional fire proofing	$ 6,091.00	6	Carpentry
4	Modify circuit breakers	$ 1,384.00	16	Electrical
5	Reroute copper pipes	$ 1,585.00	15	Mechanical
6	Added electrical conduit	$ 2,968.00	16	Electrical
7	Additional signage	$ 6,459.00	12	Furnishings
8	Modify generator power	$ 3,104.00	16	Electrical
9	Add soffit & ceiling	$ 2,626.00	6	Carpentry
10	Add smoke dampers	$ 6,781.00	15	Mechanical
	Modification Number 25	**$ 1,425,000.00**		
1	Restaurant Addition	$ 1,425,000.00		
	Modification Number 26	**$ 70,128.00**		
1	Added LED light fixtures	$ 39,040.00	16	Electrical
2	Ceiling revision	$ 2,447.00	6	Carpentry
3	Add sump pumps	$ 16,769.00	15	Mechanical
4	Door relocation	$ 7,376.00	8	Doors, Windows & Glass
5	Provide motor starter for pump	$ 1,809.00	15	Mechanical
6	Add GFCI receptacles	$ 1,795.00	16	Electrical

7	Steel support addition	$ 892.00	5	Metals
	Modification Number 27	**$ 81,881.00**		
1	Modify elevator electrical	$ 7,589.00	16	Electrical
2	Provide new breakers	$ 1,766.00	16	Electrical
3	Countertop change to Stainless	$ 1,456.00	12	Furnishings
4	Added glazing	$ 1,791.00	8	Doors, Windows & Glass
5	Restaurant TI Permits	$ 5,883.00	1	General Conditions
6	Delete condensate drip pans	$ 697.00	15	Mechanical
7	Add cast iron domes	$ 7,716.00	15	Mechanical
8	Add data ports	$ 866.00	16	Electrical
9	GWB Revision	$ 2,520.00	6	Carpentry
10	A/V equipment racks	$ 1,990.00	17	Audio/Visual
11	Add matching casework	$ 20,532.00	6	Carpentry
12	Hydro works UL listing	$ 11,910.00	15	Mechanical
13	Add rebar to plaza	$ 10,480.00	3	Concrete
14	Add station labels	$ 4,896.00	16	Electrical
15	Paint totem wall	$ 1,157.00	9	Finishes
16	Provide 2 50 amp breakers	$ 632.00	16	Electrical
	Modification Number 28	**$ (300,398.00)**		
1	Delete 4-port outlets	$ (2,898.00)	16	Electrical
2	Return of Contractor Contingency	$ (297,500.00)	1	General Conditions
	Modification Number 29	**$ 53,355.00**		
1	Add duplex receptacles	$ 2,062.00	16	Electrical
2	Audit Support	$ 1,930.00	1	General Conditions
3	Provide extra power	$ 1,067.00	16	Electrical
4	Add feminine napkin dispensers	$ 804.00	15	Mechanical
5	Provide cold water supply	$ 1,128.00	15	Mechanical
6	Add hand sink	$ 6,857.00	15	Mechanical
7	Add fire treated plywood	$ 5,185.00	6	Carpentry
8	Add stainless steel corner guards	$ 7,744.00	6	Carpentry
9	Add power for fire smoke damper	$ 2,261.00	16	Electrical
10	Add electrical for fire system	$ 17,660.00	16	Electrical
11	Fire wrap hood in concessions	$ 2,851.00	6	Carpentry
12	Add smoke detector	$ 2,431.00	16	Electrical
13	Modify lighting controls	$ 1,375.00	16	Electrical
	Modification Number 30	**$ 355,967.00**		
1	Modify tempered glass	$ 13,915.00	8	Doors, Windows & Glass
2	Modify volleyball inserts	$ 4,091.00	12	Furnishings
3	Modify wall base	$ 799.00	9	Finishes
4	Provide add. Furring	$ 1,992.00	6	Carpentry

5	Cover stair gaps	$	918.00	6	Carpentry
6	Correct Elmore road slopes	$	444.00	2	Site Work
7	Stain concrete floor	$	687.00	9	Finishes
8	New Pay & Park	$	5,057.00	16	Electrical
9	Add hand dryers	$	6,508.00	16	Electrical
10	Add data drops for TV	$	923.00	16	Electrical
11	Add electrical per MOA	$	2,930.00	16	Electrical
12	Add gym seats	$	73,286.00	12	Furnishings
13	Gym lines modification	$	1,840.00	9	Finishes
14	Add exit signs	$	1,798.00	16	Electrical
15	Add power for fire smoke damper	$	3,749.00	16	Electrical
16	Remove tempering valve	$	1,349.00	15	Mechanical
17	Change valve	$	2,069.00	15	Mechanical
18	Add CCTV	$	78,163.00	16	Electrical
19	Modify p-lam panels in concourse	$	16,437.00	9	Finishes
20	Armor seal basement concrete	$	47,928.00	9	Finishes
21	Add roller shades	$	59,541.00	16	Electrical
22	Add rooms to emergency power	$	1,024.00	16	Electrical
23	Add company switches	$	30,519.00	16	Electrical
	Modification Number 31	**$**	**154,201.00**		
1	Add dryer hand power	$	4,264.00	16	Electrical
2	Modifications to elevator shaft	$	24,701.00	14	Conveying Equipment
3	Power to scoreboard	$	1,904.00	16	Electrical
4	Audience seating hazard gaps	$	19,415.00	6	Carpentry
5	Display case coordination	$	5,030.00	6	Carpentry
6	Add light fixtures	$	1,133.00	16	Electrical
7	Lowering of gas line	$	1,538.00	2	Site Work
8	Install of unistrut	$	7,478.00	5	Metals
9	Signage change	$	6,312.00	12	Furnishings
10	Electrical revisions	$	8,906.00	16	Electrical
11	Cooling well modifications	$	21,088.00	15	Mechanical
12	Added TV locations	$	6,229.00	16	Electrical
13	Duct modifications	$	2,142.00	15	Mechanical
14	Fume hood control	$	3,537.00	15	Mechanical
15	Fire alarm revisions	$	5,358.00	16	Electrical
16	Exterior power addition	$	3,158.00	16	Electrical
17	Elevator revisions per MOA	$	6,546.00	14	Conveying Equipment
18	Add emergency power	$	2,571.00	16	Electrical
19	Electrical floor box covers	$	3,239.00	16	Electrical
20	Add speed limit signs	$	703.00	2	Site Work

21	Knox box replacement	$	946.00	12	Furnishings
22	Exterior power for A/V	$	4,536.00	16	Electrical
23	Temp. Control modifications	$	3,184.00	15	Mechanical
24	Addition of HD-SDI Camera	$	7,084.00	17	Audio/Visual
25	Revisions to fire alarm system	$	1,606.00	16	Electrical
26	Fire-smoke damper control	$	1,593.00	15	Mechanical

Appendix C. CBA Cost Model

Total Project Budget	**$ 110,585,000**		
Project Management / A&E	**$ 20,530,359**		
Total Construction Budget	**$ 90,054,641**		
Budget by Division	**Base Cost**	**Total Change**	**Total Cost**
Div. 1 General Conditions	$ 15,392,821	$ 562,567	$15,955,388
Div. 2 Site work	$ 5,385,934	$ 972,925	$ 6,358,859
Div. 3 Concrete	$ 7,803,483	$ 425,565	$ 8,229,048
Div. 4 Masonry	$ 62,040	$ -	$ 62,040
Div. 5 Metals	$ 9,559,459	$ 2,340,401	$11,899,860
Div. 6 Carpentry	$ 616,865	$ 374,760	$ 991,625
Div. 7 Moisture - Thermal Control	$ 3,132,823	$ -	$ 3,132,823
Div. 8 Doors, Windows & Glass	$ 1,001,662	$ 143,099	$ 1,144,761
Div. 9 Finishes	$ 7,891,706	$ 198,767	$ 8,090,473
Div. 10 Specialties	$ 276,322	$ 331,769	$ 608,091
Div. 11 Equipment	$ 430,072	$ -	$ 430,072
Div. 12 Furnishing	$ 1,259,555	$ 95,621	$ 1,355,176
Div. 13 Special Construction	$ -	$ -	$ -
Div. 14 Conveying Equipment	$ 552,344	$ 403,422	$ 955,766
Div. 15 Mechanical	$ 15,387,545	$ 1,270,691	$16,658,236
Div. 16 Electrical	$ 10,681,000	$ 954,028	$11,635,028
Div. 17 Audio / Visual	$ 2,383,562	$ 163,834	$ 2,547,396
Sub Totals	$ 81,817,193	$ 8,237,448	$90,054,641

							"@RISK"
			BIM Costs				
1%	to	5%	$	205,304	$	5,529,250	=RiskUniform(H3,I3)
			BIM Savings				
			Class Detection / CO Reduction				
0%	to	100%	$	-	$	562,567	=RiskUniform(H6,I6)
0%	to	100%	$	-	$	972,925	=RiskUniform(H7,I7)
0%	to	100%	$	-	$	425,565	=RiskUniform(H8,I8)
0%	to	100%	$	-	$	-	=RiskUniform(H9,I9)
0%	to	100%	$	-	$	2,340,401	=RiskUniform(H10,I10)
0%	to	100%	$	-	$	374,760	=RiskUniform(H11,I11)
0%	to	100%	$	-	$	-	=RiskUniform(H12,I12)
0%	to	100%	$	-	$	143,099	=RiskUniform(H13,I13)
0%	to	100%	$	-	$	198,767	=RiskUniform(H14,I14)
0%	to	100%	$	-	$	331,769	=RiskUniform(H15,I15)
0%	to	100%	$	-	$	-	=RiskUniform(H16,I16)
0%	to	100%	$	-	$	95,621	=RiskUniform(H17,I17)
0%	to	100%	$	-	$	-	=RiskUniform(H18,I18)
0%	to	100%	$	-	$	403,422	=RiskUniform(H19,I19)
0%	to	100%	$	-	$	1,270,691	=RiskUniform(H20,I20)
0%	to	100%	$	-	$	954,028	=RiskUniform(H21,I21)
0%	to	100%	$	-	$	163,834	=RiskUniform(H22,I22)
0%	to	100%	$	-	$	8,237,448	=SUM(J6:J22)
		ROI		-100%		**49%**	=(J23-J3)/J3+RiskOutput("Return on Investment")
		Cost (+/-)	$	**(205,304)**	$	**2,708,198**	=J23-J3+RiskOutput("Est. Cost +/-")

Appendix D. CBA Schedule Model

		ACTUAL		
WBS	**Name**	**Start**	**Finish**	**Duration**
1	**UAA Sports Arena**	**10/10/2011**	**8/1/2014**	**735**
1.1	Pre-Award	10/10/2011	1/20/2012	75
1.2	**Pre-Construction Services**	**1/23/2012**	**2/27/2013**	**288**
1.2.1	Design - Site & Structural	1/23/2012	12/6/2012	229
1.2.2	Design - Arch., Mech., Elec.,	1/23/2012	2/27/2013	288
1.2.3	Final Design & GMP	8/27/2012	11/29/2012	69
1.3	**Construction Services**	**1/23/2012**	**8/1/2014**	**660**
1.3.1	Quality Control	1/23/2012	8/1/2014	660
1.3.2	Procurement	7/2/2012	3/2/2014	436
1.3.3	Phase 1 Site Development	4/16/2012	6/30/2014	576
1.3.4	Phase 2 Structural Erection	8/13/2012	9/11/2013	283
1.3.5	Phase 3 Build Out & Completion	2/7/2013	6/9/2014	348
1.3.6	Phase 4 Commissioning & Closeou	5/5/2014	8/1/2014	65
1.3.7	Project Completion	8/1/2014	8/1/2014	0
	Total Construction Budget	$ 90,054,641		
	Daily Burn Rate (Cost Per Day)	$ 122,523.32		

	O	P	ML	OPTIMISTIC			PESSIMISTIC		
WBS	**Est +/-**	**Est +/-**	**Est +/-**	**Start**	**Finish**	**Duration**	**Start**	**Finish**	**Duration**
1				**10/10/2011**	**7/2/2014**	**713**	**10/10/2011**	**8/4/2014**	**736**
1.1	0.0	0.0		10/10/2011	1/20/2012	75	10/10/2011	1/20/2012	75
1.2				**1/23/2012**	**2/28/2013**	**288**	**1/23/2012**	**3/28/2013**	**308**
1.2.1	0.0	16.0	8.0	1/23/2012	12/7/2012	229	1/23/2012	12/31/2012	245
1.2.2	0.0	20.2	10.1	1/23/2012	2/28/2013	288	1/23/2012	3/28/2013	308
1.2.3	0.0	4.8	2.4	8/27/2012	11/30/2012	69	8/27/2012	12/6/2012	74
1.3				**1/23/2012**	**7/2/2014**	**638**	**1/23/2012**	**8/4/2014**	**661**
1.3.1	0.0	0.0	0.0	1/23/2012	7/2/2014	638	1/23/2012	8/4/2014	661
1.3.2	0.0	0.0	0.0	7/2/2012	2/18/2014	436	7/2/2012	3/3/2014	436
1.3.3	9.0	0.0	4.5	4/16/2012	6/18/2014	567	4/16/2012	7/1/2014	576
1.3.4	8.9	0.0	4.5	8/13/2012	8/30/2013	274	8/13/2012	9/12/2013	283
1.3.5	15.4	0.0	7.7	2/7/2013	5/19/2014	333	2/7/2013	6/10/2014	348
1.3.6	6.5	0.0	3.3	4/13/2014	7/2/2014	59	5/5/2014	8/4/2014	65
1.3.7	39.8	-41.0	-0.6		7/2/2014			8/4/2014	
					Total Duration +/-	22		**Total Duration +/-**	-1
					Cost +/-	$2,695,513		**Cost +/-**	$(122,523)

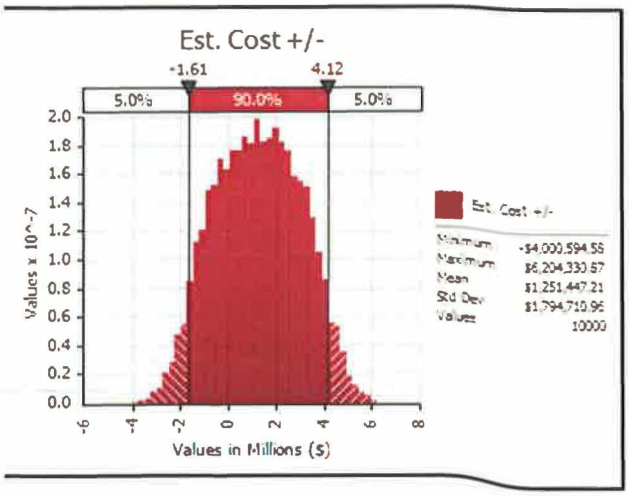
	Most Likely			"@RISK"
WBS	Start	Finish	Duration	
1	**10/10/2011**	**7/17/2014**	**724**	**=MAX(AS5:AS15)+AS4**
1.1	10/10/2011	1/20/2012	75	=RiskTriang(AL4,AR4,AO4)
1.2	**1/23/2012**	**3/14/2013**	**298**	**=MAX(AS6:AS8)**
1.2.1	1/23/2012	12/19/2012	237	=RiskTriang(AL6,AR6,AO6)
1.2.2	1/23/2012	3/14/2013	298	=RiskTriang(AL7,AR7,AO7)
1.2.3	8/27/2012	12/4/2012	71	=RiskTriang(AL8,AR8,AO8)
1.3	**1/23/2012**	**7/17/2014**	**649**	**=MAX(AS10:AS15)**
1.3.1	1/23/2012	7/17/2014	649	=NETWORKDAYS(AP10,AT10,)
1.3.2	7/2/2012	2/24/2014	436	=RiskTriang(AL11,AR11,AO11)
1.3.3	4/16/2012	6/24/2014	572	=RiskTriang(AL12,AR12,AO12)
1.3.4	8/13/2012	9/5/2013	279	'=RiskTriang(AL13,AR13,AO13)
1.3.5	2/7/2013	5/29/2014	340	=RiskTriang(AL14,AR14,AO14)
1.3.6	4/23/2014	7/17/2014	62	=RiskTriang(AL15,AR15,AO15)
1.3.7		7/17/2014		
	Total Duration +/-		11	=$E$3-AS3+RiskOutput("Duration Change")
		Cost +/-	$1,347,757	**=$C$20*AS19+RiskOutput("Cost Change")**

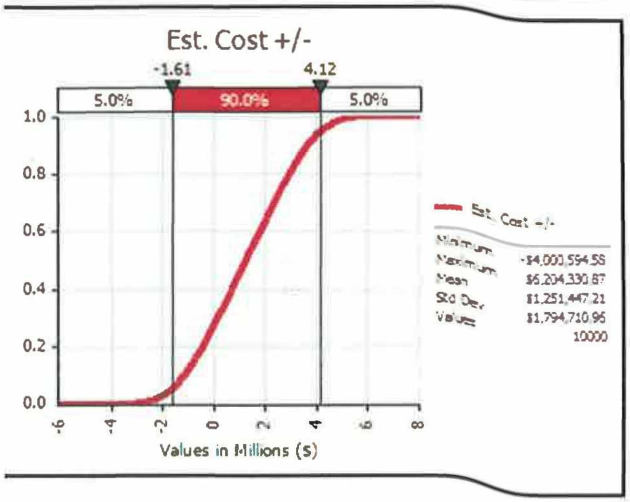
Appendix E. CBA @RISK Cost Model Outputs

@RISK Output Report for Est. Cost +/-

Performed By: Michael Fisher

Date: Tuesday, November 04, 2014 2:34:09 PM

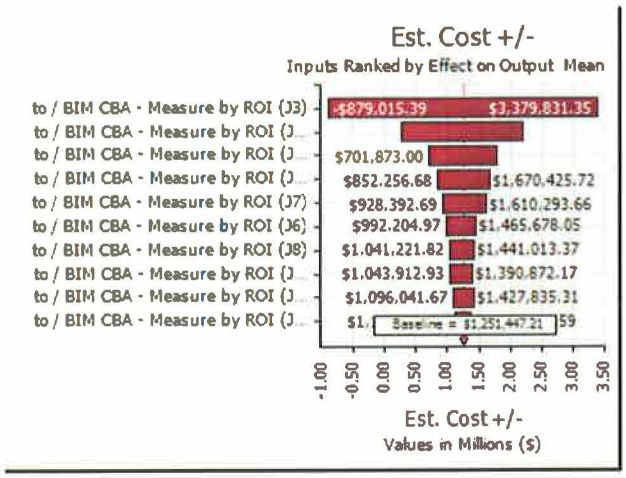




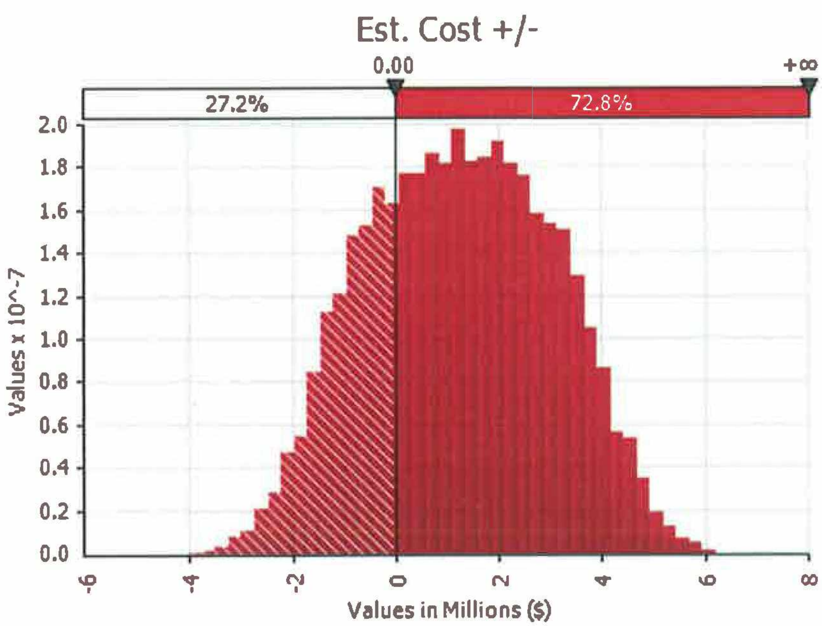
Simulation Summary Information	
Workbook Name	McConnell Chris - ESM 684 Mo
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	27
Number of Outputs	4
Sampling Type	Latin Hypercube
Simulation Start Time	11/4/2014 14:33
Simulation Duration	00:00:05
Random # Generator	Mersenne Twister
Random Seed	1139757683

Summary Statistics for Est. Cost +/-

Statistics		Percentile	
Minimum	$ (4,000,595)	**5%**	$ (1,612,579)
Maximum	$ 6,204,331	**10%**	$ (1,138,830)
Mean	$ 1,251,447	**15%**	$ (765,322)
Std Dev	$ 1,794,711	**20%**	$ (432,168)
Variance	3.22099E+12	**25%**	$ (132,744)
Skewness	-0.002070612	**30%**	$ 161,876
Kurtosis	2.305825881	**35%**	$ 446,733
Median	$ 1,260,464	**40%**	$ 719,928
Mode	$ 1,241,104	**45%**	$ 996,584
Left X	$ (1,612,579)	**50%**	$ 1,260,464
Left P	5%	**55%**	$ 1,529,887
Right X	$ 4,123,131	**60%**	$ 1,796,001
Right P	95%	**65%**	$ 2,056,881
Diff X	$ 5,735,710	**70%**	$ 2,337,056
Diff P	90%	**75%**	$ 2,611,900
#Errors	0	**80%**	$ 2,926,400
Filter Min	Off	**85%**	$ 3,258,310
Filter Max	Off	**90%**	$ 3,621,435
#Filtered	0	**95%**	$ 4,123,131



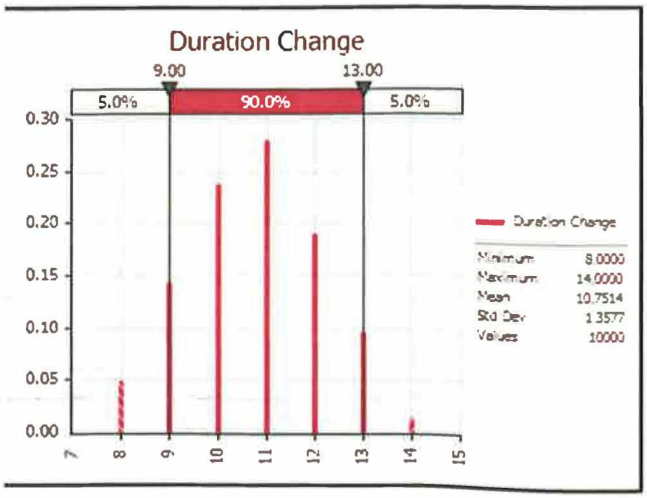
Change in Output Statistic for Est. Cost +/-			
Rank	Name	Lower	Upper
1	to / BIM CBA - Me	$ (879,015)	$ 3,379,831
2	to / BIM CBA - Me	$ 277,108	$ 2,204,876
3	to / BIM CBA - Me	$ 701,873	$ 1,787,864
4	to / BIM CBA - Me	$ 852,257	$ 1,670,426
5	to / BIM CBA - Me	$ 928,393	$ 1,610,294
6	to / BIM CBA - Me	$ 992,205	$ 1,465,678
7	to / BIM CBA - Me	$ 1,041,222	$ 1,441,013
8	to / BIM CBA - Me	$ 1,043,913	$ 1,390,872
9	to / BIM CBA - Me	$ 1,096,042	$ 1,427,835
10	to / BIM CBA - Me	$ 1,116,984	$ 1,373,014

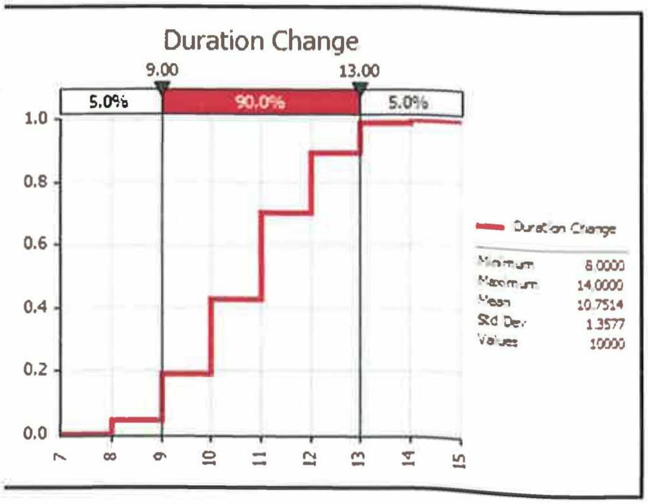


Appendix F. CBA @RISK Schedule Model Outputs

@RISK Output Report for Duration Change

Performed By: Michael Fisher
Date: Tuesday, November 04, 2014 2:34:11 PM

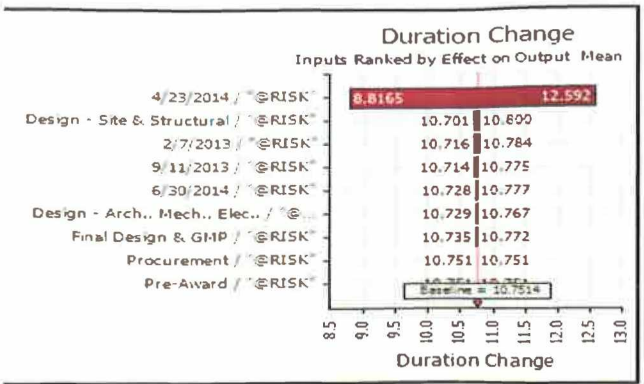




Simulation Summary Information	
Workbook Name	McConnell Chris - ESM 68
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	27
Number of Outputs	4
Sampling Type	Latin Hypercube
Simulation Start Time	11/4/2014 14:33
Simulation Duration	00:00:05
Random # Generator	Mersenne Twister
Random Seed	1139757683

Summary Statistics for Duration Change

Statistics		Percentile	
Minimum	8	5%	9
Maximum	14	10%	9
Mean	11	15%	9
Std Dev	1	20%	10
Variance	1.843382378	25%	10
Skewness	0.002006795	30%	10
Kurtosis	2.449122251	35%	10
Median	11	40%	10
Mode	11	45%	11
Left X	9	50%	11
Left P	5%	55%	11
Right X	13	60%	11
Right P	95%	65%	11
Diff X	4	70%	11
Diff P	90%	75%	12
#Errors	0	80%	12
Filter Min	Off	85%	12
Filter Max	Off	90%	13
#Filtered	0	95%	13

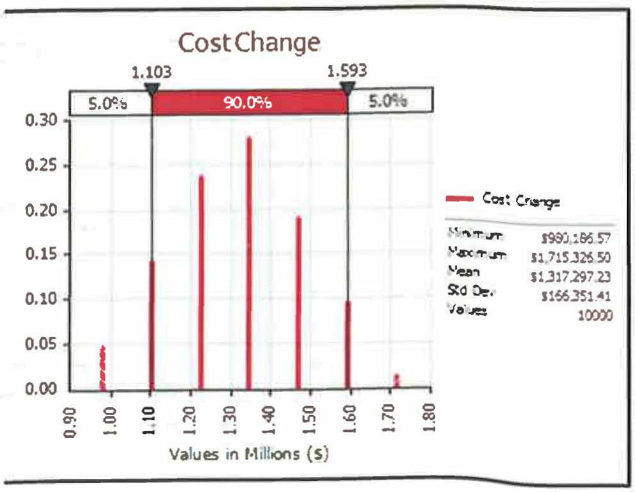


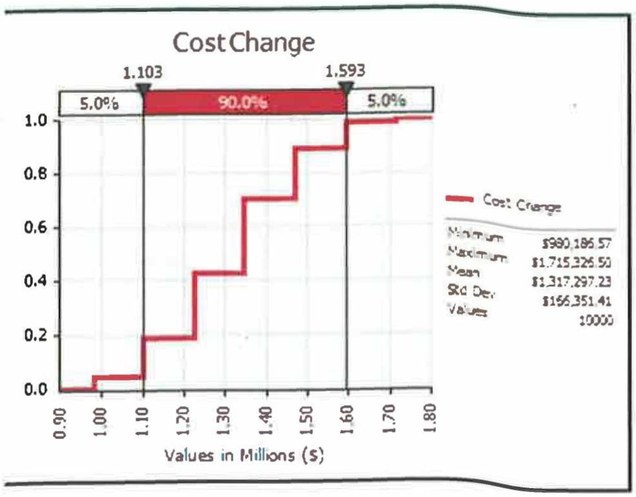
Change in Output Statistic for Duration Change			
Rank	**Name**	**Lower**	**Upper**
1	4/23/2014 / "@R	9	13
2	Design - Site & St	11	11
3	2/7/2013 / "@RIS	11	11
4	9/11/2013 / "@R	11	11
5	6/30/2014 / "@R	11	11
6	Design - Arch., M	11	11
7	Final Design & G	11	11
8	Procurement / "@	11	11
9	Pre-Award / "@R	11	11

@RISK Output Report for Cost Change

Performed By: Michael Fisher

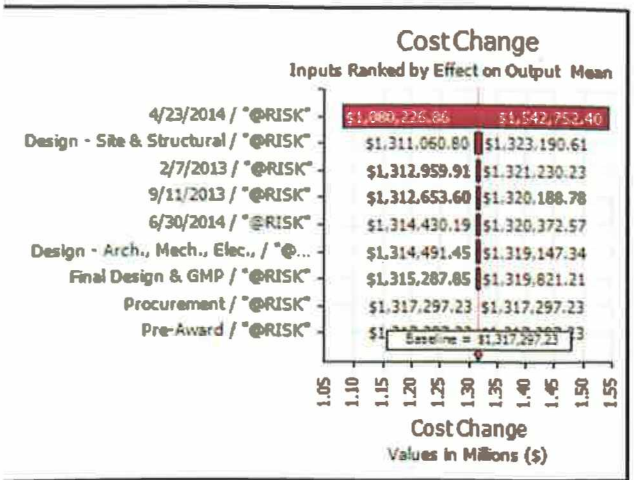
Date: Tuesday, November 04, 2014 2:34:13 PM





Simulation Summary Information	
Workbook Name	McConnell Chris - ESM 684 M
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	27
Number of Outputs	4
Sampling Type	Latin Hypercube
Simulation Start Time	11/4/2014 14:33
Simulation Duration	00:00:05
Random # Generator	Mersenne Twister
Random Seed	1139757683

Summary Statistics for Cost Change			
Statistics		**Percentile**	
Minimum	$ 980,187	**5%**	$ 1,102,710
Maximum	$ 1,715,326	**10%**	$ 1,102,710
Mean	$ 1,317,297	**15%**	$ 1,102,710
Std Dev	$ 166,351	**20%**	$ 1,225,233
Variance	27672790288	**25%**	$ 1,225,233
Skewness	0.002006795	**30%**	$ 1,225,233
Kurtosis	2.449122251	**35%**	$ 1,225,233
Median	$ 1,347,757	**40%**	$ 1,225,233
Mode	$ 1,347,757	**45%**	$ 1,347,757
Left X	$ 1,102,710	**50%**	$ 1,347,757
Left P	5%	**55%**	$ 1,347,757
Right X	$ 1,592,803	**60%**	$ 1,347,757
Right P	95%	**65%**	$ 1,347,757
Diff X	$ 490,093	**70%**	$ 1,347,757
Diff P	90%	**75%**	$ 1,470,280
#Errors	0	**80%**	$ 1,470,280
Filter Min	Off	**85%**	$ 1,470,280
Filter Max	Off	**90%**	$ 1,592,803
#Filtered	0	**95%**	$ 1,592,803

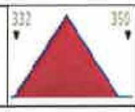
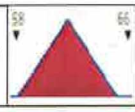
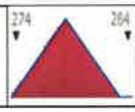
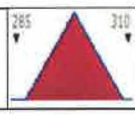
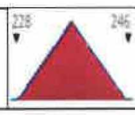
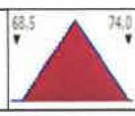
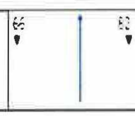


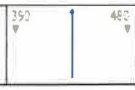
Change in Output Statistic for Cost Change			
Rank	Name	Lower	Upper
1	4/23/2014 / "@R	$ 1,080,227	$ 1,542,752
2	Design - Site & St	$ 1,311,061	$ 1,323,191
3	2/7/2013 / "@RIS	$ 1,312,960	$ 1,321,230
4	9/11/2013 / "@R	$ 1,312,654	$ 1,320,189
5	6/30/2014 / "@R	$ 1,314,430	$ 1,320,373
6	Design - Arch., M	$ 1,314,491	$ 1,319,147
7	Final Design & G	$ 1,315,288	$ 1,319,821
8	Procurement / "@	$ 1,317,297	$ 1,317,297
9	Pre-Award / "@R	$ 1,317,297	$ 1,317,297

Appendix G. CBA @RISK Input Results

@RISK Input Results

Performed By: Michael Fisher
Date: Tuesday, November 04, 2014 2:34:15 PM

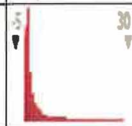
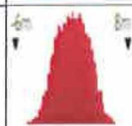
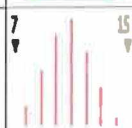
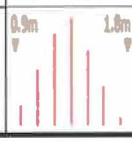
Name	Worksheet	Cell	Graph	Min	Mean	Max	5%	95%	Errors
Category: 2/7/2013									
2/7/2013 / "@RISK"	Schedule Model	AS14		333	340	348	335	346	0
Category: 4/23/2014									
4/23/2014 / "@RISK"	Schedule Model	AS15		59	62	65	60	64	0
Category: 6/30/2014									
6/30/2014 / "@RISK"	Schedule Model	AS12		567	572	576	568	575	0
Category: 9/11/2013									
9/11/2013 / "@RISK"	Schedule Model	AS13		274	279	283	275	282	0
Category: Design - Arch., Mech., Elec.,									
Design - Arch., Mech., Elec., / "@RISK"	Schedule Model	AS7		288	298	308	291	305	0
Category: Design - Site & Structural									
Design - Site & Structural / "@RISK"	Schedule Model	AS6		229	237	245	232	242	0
Category: Final Design & GMP									
Final Design & GMP / "@RISK"	Schedule Model	AS8		69	71	74	70	73	0
Category: Pre-Award									
Pre-Award / "@RISK"	Schedule Model	AS4		75	75	75	75	75	0

Category: Procurement										
	Procurement / "@RISK"	Schedule Model	AS11		436	436	436	436	436	0
Category: to										
	to / BIM CBA - Measure by ROI	CBA by Division	J3		205487.5	2867276	5528980	470985.7	5263021	0
	to / BIM CBA - Measure by ROI	CBA by Division	J6		54.06971	281283.6	562550.9	28082.65	534416.3	0
	to / BIM CBA - Measure by ROI	CBA by Division	J7		65.10957	486462.4	972873.3	48551.82	924242.1	0
	to / BIM CBA - Measure by ROI	CBA by Division	J8		37.91545	212782	425562.8	21259.23	404246.2	0
	to / BIM CBA - Measure by ROI	CBA by Division	J9		0	0	0	0	0	0
	to / BIM CBA - Measure by ROI	CBA by Division	J10		15.95781	1170200	2340326	116947.5	2223222	0
	to / BIM CBA - Measure by ROI	CBA by Division	J11		5.138106	187380	374728.4	18709.29	355997.5	0
	to / BIM CBA - Measure by ROI	CBA by Division	J12		0	0	0	0	0	0
	to / BIM CBA - Measure by ROI	CBA by Division	J13		10.65873	71549.51	143091.5	7152.585	135942.5	0
	to / BIM CBA - Measure by ROI	CBA by Division	J14		12.70109	99383.59	198751.5	9925.897	188817.2	0
	to / BIM CBA - Measure by ROI	CBA by Division	J15		30.04446	165884.6	331750.1	16573.44	315173.9	0
	to / BIM CBA - Measure by ROI	CBA by Division	J16		0	0	0	0	0	0
	to / BIM CBA - Measure by ROI	CBA by Division	J17		3.27855	47810.5	95617.1	4780.566	90831.63	0
	to / BIM CBA - Measure by ROI	CBA by Division	J18		0	0	0	0	0	0
	to / BIM CBA - Measure by ROI	CBA by Division	J19		6.883366	201711.1	403420.3	20147.54	383216.5	0
	to / BIM CBA - Measure by ROI	CBA by Division	J20		24.32062	635344.9	1270578	63474.03	1207118	0
	to / BIM CBA - Measure by ROI	CBA by Division	J21		47.95105	477013.9	953990	47676.64	906317.6	0
	to / BIM CBA - Measure by ROI	CBA by Division	J22		6.852954	81917.05	163817.9	8185.628	155636.6	0

Appendix H. CBA @RISK Output Results

@RISK Output Results

Performed By: Michael Fisher
Date: Tuesday, November 04, 2014 2:34:17 PM

Name	Worksheet	Cell	Graph	Min	Mean	Max	5%	95%	Errors
Return on Investment	CBA by Division	J24		-0.7261919	1.551548	27.89481	-0.3394271	7.743881	0
Est. Cost +/-	CBA by Division	J25		$ (4,000,595)	$ 1,251,447	$ 6,204,331	$ (1,612,579)	$ 4,123,132	0
Duration Change	Schedule Model	AS19		8	11	14	9	13	0
Cost Change	Schedule Model	AS20		$ 980,187	$ 1,317,297	$ 1,715,327	$ 1,102,710	$ 1,592,803	0